COMMERCIAL EARTH OBSERVATION SATELLITES

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ABSTRACT:

In the summer 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 initiates a new era of commercial Earth observation satellites which may well revolutionize the infrastructure, processes and products of the entire photogrammetric/remote sensing/GIS community. Currently several companies in the USA; EarthWatch, Space Imaging, Orbital Sciences, GDE and Resource 21 have imaging satellites under development and are establishing international strategic partnerships for reception, value-added processing, distribution and sales. In aggregate, these and other proposed electro-optical systems will produce digital panchromatic images with spatial resolutions of one to three meters and from four to fifteen meters in the multispectral bands. These digital systems are highlighted by their flexible pointing ability, high geometric fidelity and very rapid image-collection to customer-delivery. A summary of the operational capabilities, technical characteristics and some relevant issues are discussed for six different commercial sensor systems. In addition a commentary and prognostication of the impact on the photogrammetric/remote sensing/GIS community are offered including on market projections.

INTRODUCTION

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 has decided to take the initiative.

As you may recall, ever since the first artificial satellite has been placed in Earth orbit there have been three most promising areas for space commercialization -- communications, remote sensing, and materials processing. The commercial satellite Communications industry was spawned from government operations in the early 1960's and has prospered ever since. Materials Processing in space is still in experimental stages and has yet to mature into a viable commercial activity. And as you will read below, Remote Sensing from satellites is just passing the threshold into maturity as a commercial space activity. A review of existing Earth observation satellites will not be given herein. 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, IRS-C and Resurs-F.

Traditionally, Earth observation satellites have been categorized into three types: Reconnaissance, Meteorological, and Earth Resources. A fourth type, Commercial satellites, will soon be launched. Over the next ten years, 1996-2005, there are known plans for the launch of more than 100 Earth observation satellites of all types, plus several Cosmos satellites per year. Sixty Earth observation satellites are scheduled for launch before the end of 1999 and this number is expected to increase.

One may ask, 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 what is termed "dual-use" technology. That is, a use of previously proven defense technology applied to civil applications. The sales of imagery produced by former Russian reconnaissance systems is a prime example. Another reason for commercialization is the unfortunate failure to orbit Landsat 6, and the end of useful operability of Landsat 4. Landsat and SPOT have received US and French government support but have not achieved the commercial successes for which many had hoped. Market projections by commercial firms now link the promise of geo-spatial information systems (GIS) to the markedly reduced costs of developing and launching satellites, resulting in very attractive market opportunities. Then there are the continual advancements in digital technology (for example, a 7000 by 9000 full frame CCD for sensors was just announced by Philips Imaging Technology) which allow satellite systems, which easily could have cost one billion US dollars ten years ago, to be built now for under 100 million dollars.

In the USA, the 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 will have the capability to provide better than one-meter spatial resolution by the year 1998. The developers and their partners are positioning themselves to serve an expected $2 billion annual commercial imaging market in the year 2000. Currently the satellite and aircraft imaging market is estimated to be about $700 million.

The foremost driver of commercial Earth imagery products now is the progression of "The Information Age." Today's society craves information. Although information for traditional public products, such as maps, would often take seven years to produce from the planning stage, it is clear that in today's society this delay is unacceptable. In addition, the GIS and the new, innovative niche markets such as "precision farming" 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. These insatiable spatial information needs, as exemplified by the myriad of new GPS applications, will include the imaging market. Properly packaged, the benefits of commercial digital imaging satellites can readily satisfy consumer demands, especially for geo-spatial information. It has been projected that as much as 80% of the information used in decision-making processes has geo-based context.

Given this rationale and the positive 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 establish the system infrastructures needed to sustain full service imaging data and product capabilities.

The following sections outline a current summary of the technical characteristics and infrastructure strategies of several commercial Earth observation systems.

EARTHWATCH INCORPORATED

The merger of the commercial remote sensing activities of the former WorldView Imaging Corporation with the Ball Aerospace & Technology Corp. brought together two distinctively different technical approaches. Combined, their EarthWatch Inc. provides a formidable constellation of imaging systems to address the breadth of the applications market. EarthWatch headquarters are located in Longmont, Colorado. It is managed by Dr. Richard Herring, Chief Executive Officer, a Senior Vice President from Ball Aerospace; 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 two types of 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 August 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. The image collection capabilities of EarlyBird and QuickBird in near-polar (97.3°) and high inclination (52°) orbits simultaneously will provide consumers many options as shown in figure 1.

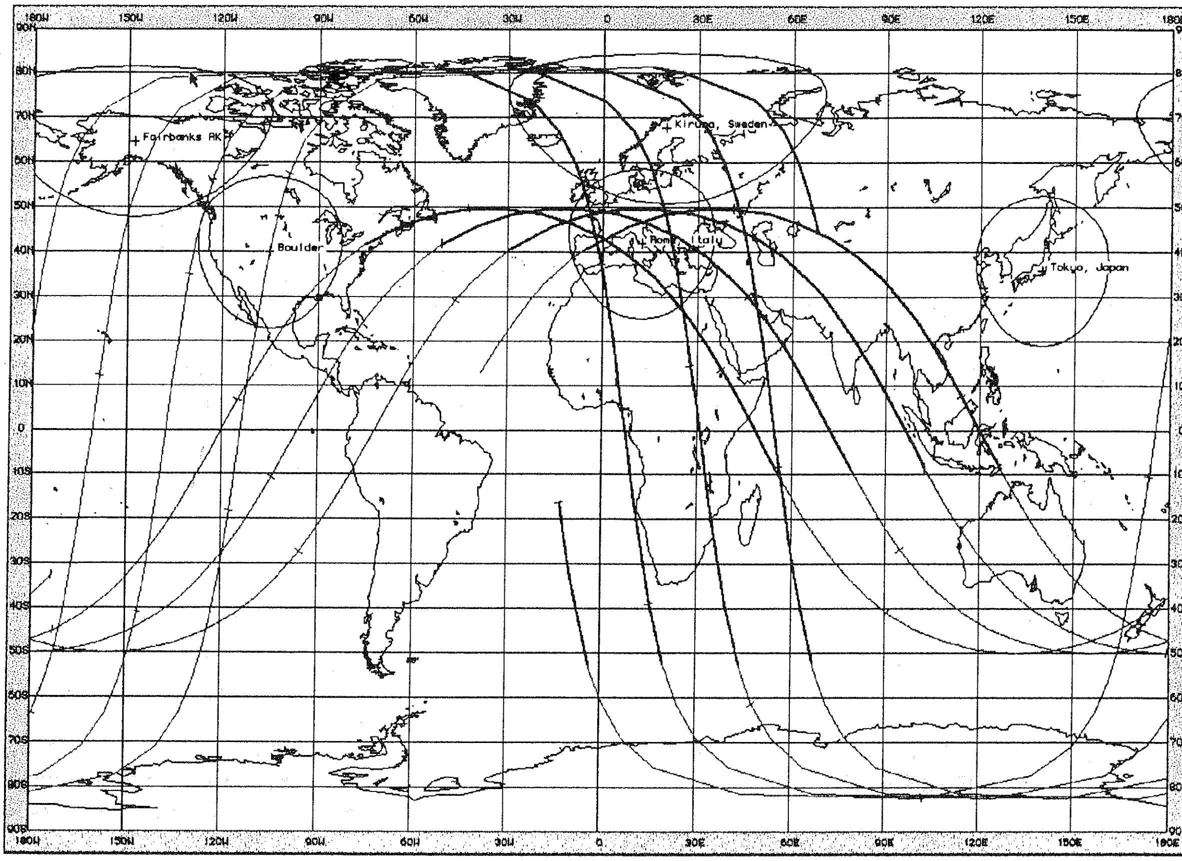

Figure 1. Simultaneous 3-meter and 1-meter EarthWatch Satellites Permits New Competitive Orbit Options

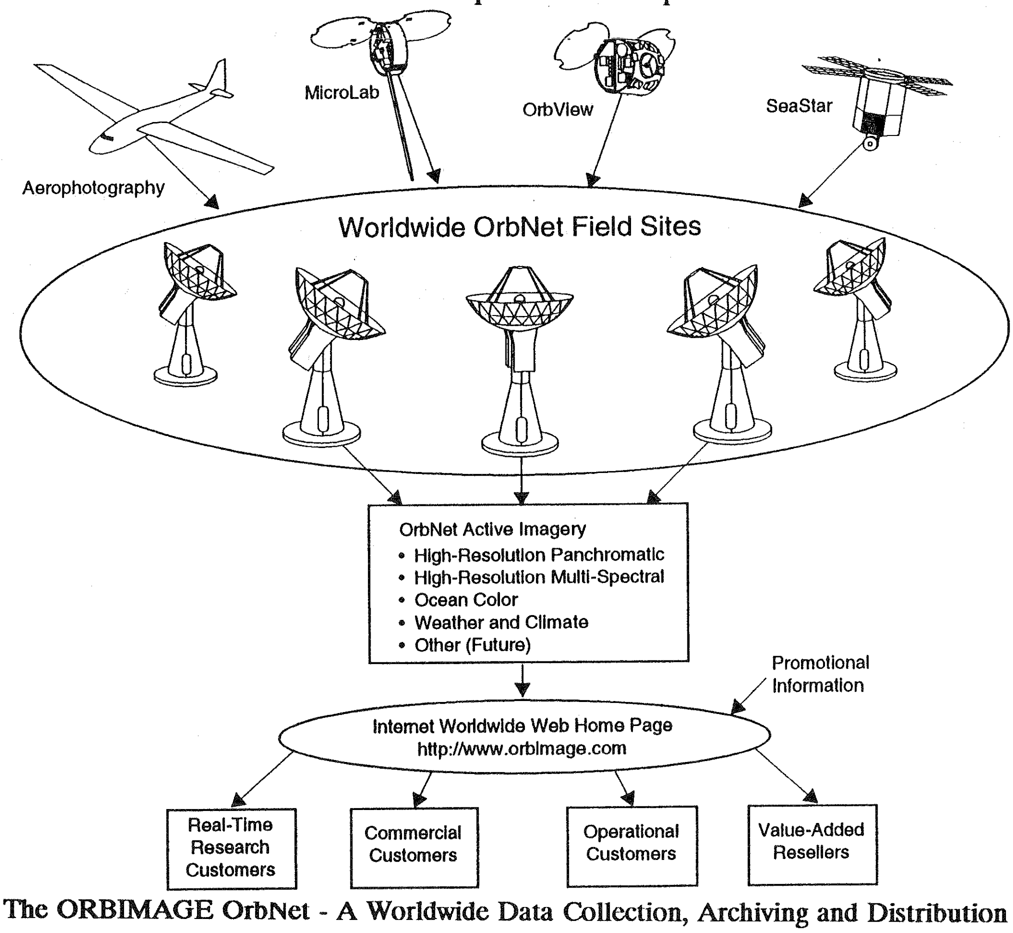

Figure 2. The ORBIMAGE OrbNet - A Worldwide Data Collection, Archiving and Distribution System

Unlike its competitors, EarthWatch Inc. has stated 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 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. EarthWatch image products include: Precision-Corrected images; Terrain-Corrected images; Digital Terrain Models (DTM's); and Perspective Views; with Catalog and Image Subscription Services.

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. "SeaStar," the first of its imaging systems, will be launched in mid 1996 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 plan is 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 a four-meter resolution multispectral sensor which will share a common aperture. OrbView-1 is scheduled for a Pegasus launch in the Fall of 1997 and has a design/expected life of three to five years. It features an electro-optical camera that has capability to image scenes 45° off axis in all directions. Such flexibility provides an average revisit time, for an area of repetitive interest, 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. Combining photo identifiable control with OrbView-1's high resolution stereo imager enables 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 imagery in real-time and to archive 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, digital terrain models, stereopairs, image enhancements, perspective scenes, etc. ORBIMAGE will archive and disseminate data to its distributors through ORBNET, (See Figure 2.) a commercial communications service company of Orbital Sciences Corp. which is scheduled to commence service 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, Colorado having relocated from Sunnyvale, California. Formed initially by Lockheed Missiles and Space Co., Space Imaging is now an independent corporation of which Lockheed Martin Corp., E-Systems, Inc. and Mitsubishi Corp. are minority partners. Space Imaging is directed by J. R. Copple, CEO and John Neer, President.

The Space Imaging system is designed to cover large area swaths of high resolution imagery from its 680 km orbit. The system has a very expansive field of regard, 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 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!

As shown in figure 3, the ground station uplinks to the satellite contain user requested latitude/longitude bounds, desired bandwidth and tasking (imaging) priorities. The fore and aft collection of overlapping swaths provides optimal base height ratios enabling a stereo scene to be imaged on the same orbital pass, plus opportunities to acquire additional images during the same time frame are available. System users receive confirmation of tasking, and subsequently receive the imagery and its metadata for processing.

Space Imaging, Inc. 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 acquisitions. 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 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 2 m horizontal accuracy); *Orthorectified* - precision geometrically corrected including terrain elevation data to support up to 1:2,400 scale orthophotos; *DTM's* - 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.

Space Imaging is providing a capability for customers to browse reduced-resolution imagery in the Space Imaging$^{TM/SM}$ archive to preview for specific criteria such as cloud cover, location, ground sample distance, etc.

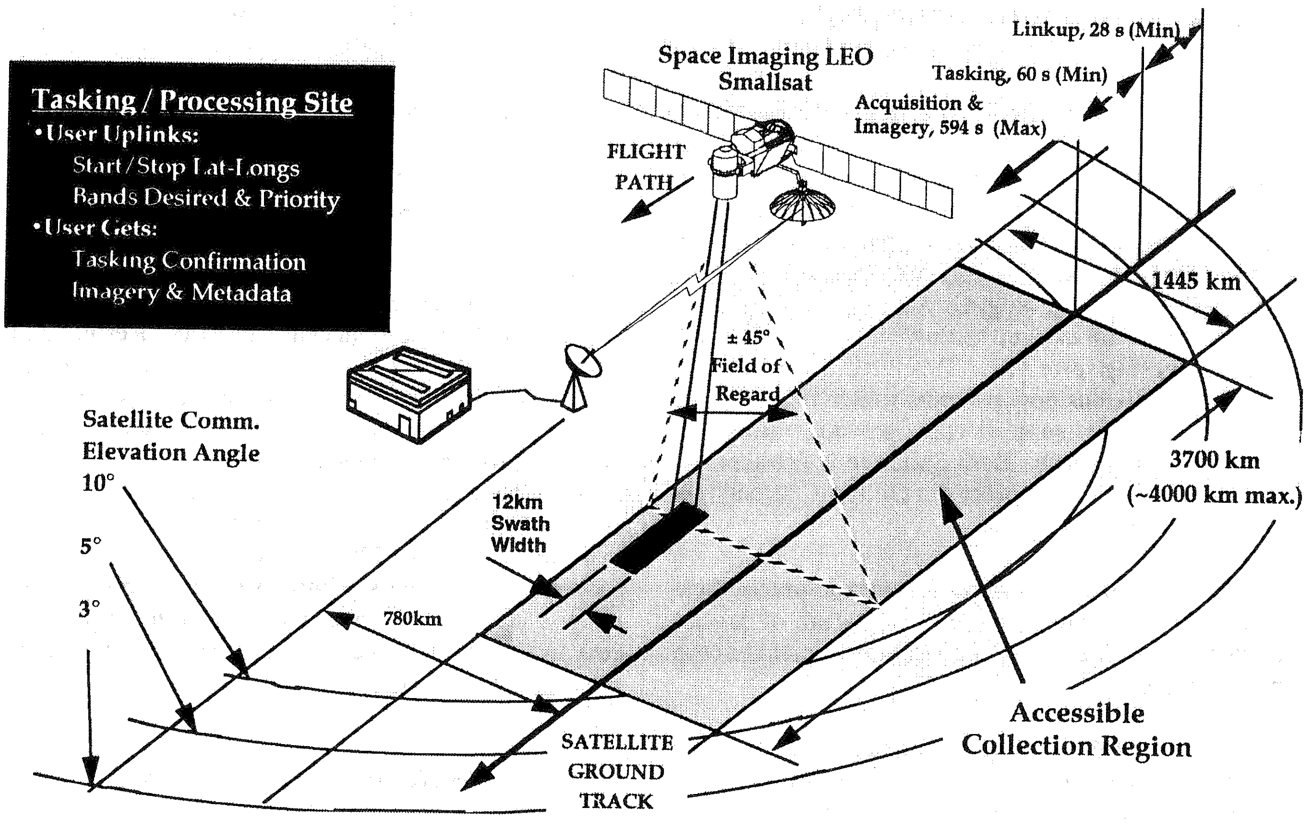

Figure 3. Space Imaging - Typical Tasking Scenario

GDE SYSTEMS, INC.

GDE Systems was an original principal in the now defunct Eyeglass group venture. Under the management of Dr. Phil Currier, GDE Systems obtained its license in June 1995 to operate an 0.85 m panchromatic sensor system. GDE Systems is a Division of the Tracor Company and is well known for its successful development of the Helava digital image workstations for precision photogrammetric image processing.

The GDE high resolution imaging system is in its preliminary stages of design and only limited information is available on its technical characteristics and products. Its launch target date is set for late 1999. This high resolution system is being designed to acquire monoscopic imagery in 15 km by 1,700 km strips or in 120 km by 120 km patches. It also can acquire same pass stereoscopic imagery in 15 km by 700 km strips or in 70 km by 70 km patches. Current assumptions for system technical characteristics are shown in Tables 4-7.

The proposed GDE System management plan is to license regional franchise affiliates which are linked with imagery reception sites. These regional partners will maintain local imagery archives and provide value-added image product and distribution capabilities. The primary processing center and master archive will be managed by GDE in the USA. Their plan is to provide Internet accessibility and two-day delivery from time of image acquisition. The product suite plan is to provide system corrected images; geometric corrected images; monoscopic scenes tailored to customer needs; stereo image pairs; DTM's; orthophoto and special image products; and volume discounted pricing.

RESOURCE 21

Resource 21 is a commercial remote sensing information systems and services company which has obtained a commercial license to develop and operate a constellation of ten meter resolution multispectral satellites for initial operational capability in the early months of 1999. Resource 21 was created in 1994 by the Institute of Technology Development (ITD) based on four years of market testing of an aircraft-based remote sensing product. Resource 21 is now a coalition of six business partners which are designing their system to support the growing "precision farming" industry. Dr. Herb Satterlee is President of Resource 21 which has offices in Gulfport, Mississippi and Denver, Colorado.

Precision farming is the determination of precise field conditions for managing the dispensation of precise nutrients to precise locations for improvement of crop productivity.

In October 1996, Resource 21 will make a go-ahead decision to begin construction of five satellites. Its initial constellation will have four satellites in orbit by early 1999. The four satellites will be placed in exactly the same orbital plane, but with tightly controlled phasing. The phasing will result in two satellites in each of two ground tracks that repeat every seven days. Each of the two satellites within a particular ground track revisit, with the same access geometry, the same ground sites every third or fourth day. This strategy results in twice weekly "nadir" access revisits of all sites.

The multispectral, pushbroom sensor called "M10" is nominally designed for nadir collection of 205 km swaths, but it has adjustable line rates to accommodate off-nadir collection. The spacecraft bus can roll or tilt the sensor allowing stereo imaging and frequency of site revisits up to three times daily! The spatial resolution of the MS system is 10m (1/40th acre) nominally designed to provide precise monitoring of ¼ acre sites for 180 acre or larger farms. Precision digital processing of the MS bands (e.g. band ratio comparisons) provides information about the temporal condition of crops and soils for frequent remote monitoring of localized variations in site conditions such as; moisture content, pest and weed infestations, and nutrient needs.

With the use of ground control points, it is projected that spatial accuracies of better than 5 m absolute and 1 m relative can be provided. A site/region specific GIS will maintain site condition history. This potent combination of information allows timely allocation of water, fertilizer, pesticides, etc. thereby vastly increasing site productivity. The system is ideally suited for agricultural sites which use farm equipment instrumented with GPS. A pilot program using airborne MS sensors, conducted since 1991, includes more than 180 "beta" sites in six states to demonstrate the effectiveness of approach. Future efforts to expand into non-agricultural markets are under consideration.

Table 8 provides a summary of the Resource 21 technical and operational characteristics. Resource 21 is offering: *Products* - data, information, and tools; *Services* - custom processing, special studies, training, and delivery; and *Ordering Options* - subscriptions, archive retrievals, standard information products, custom area quantity and shapes, custom and standard formats. The ground processing system is designed to provide twice weekly information products to subscribing customers within two to six hours after image acquisition! Typical costs are $6 to 15 per acre cost to the farmer, wherein the price is set per value per crop grower type.

OTHER PROPOSED SYSTEMS

Although system plans and technical specifications are not available at this time, another commercial remote sensing satellite system is under development by the Geophysical & Environmental Research Corp. (GER) of Millbrook, New York. The GER Earth Resource Observation System "GEROS" will include a constellation of six simultaneous satellites each carrying a 10m MS and < 10m pan digital sensor. GEROS is being developed for the agricultural market with initial emphasis for precision farming.

Other non-USA commercial digital Earth observing systems have been under consideration in several countries such as South Africa, Israel, and Russia. However, except for the Greensat Program of South Africa, most are being funded by governments rather than totally funded by private organizations.

Corporation "System"	EarthWatch "EarlyBird"		EarthWatch "QuickBird"		Orbital Sciences "OrbView-1"		Space Imaging		GDE
Partners	Ball Aerospace & Technology Corp. Hitachi Ltd. Nuova Telespazio s.p.a. CTA Space Systems, Inc. Datron Systems Inc. MacDonald, Dettwiler & Assoc., Ltd.				Orbital Sciences EIRAD Co. Ltd. PE Applied Sci. Fairchild Systems MDA, Ltd.		Lockheed Martin E-Systems Mitsubishi		TBA
On-Orbit date	Aug 1996		July 1997		Dec 1997		Dec 1997		Late 1999
Imager Type	Staring Array		Pushbroom		Pushbroom		Pushbroom		Pushbroom
Payload	< 100 kg		~ 150 kg		150 kg		~ 225-275 kg		TBA (Lightsat)
Mode	**Pan**	**MS**	**Pan**	**MS**	**Pan**	**MS**	**Pan**	**MS**	**Pan**
Pixels	8 bit	8 bit x 3 arrays	11 bit	11 bit x 4 arrays	8 bit	8 bit	11 bit	11 bit	11 bit
Data Size	4MB	12MB	3.5Gb	14.2Gb	128Mb	128Mb	TBA	TBA	TBA

Table 4. High Resolution Commercial Earth Observing Satellites
- General Information -

Corporation "System"	EarthWatch "EarlyBird"		EarthWatch "QuickBird"		Orbital Sciences "OrbView-1"		Space Imaging		GDE
Mode	**Pan**	**MS**	**Pan**	**MS**	**Pan**	**MS**	**Pan**	**MS**	**Pan**
Resolution (Nadir GSD)	3 m	15 m	1 m	4 m	1 & 2m	4 m	.82 m	4 m	.8 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	.50 -.90
Swath width	6 km	30 x 30 km	36 km		4 & 8 km	8 km	11 km		≥15 km
Scene size at nadir (stereo)	36km^2	900km^2	36km x 36km		8km x 8km		60km x 60km		70km x 70km
Field of View	TBA		TBA		1°		.93°		≥1.2°
Stereo	In track		In track		In track		In & crosstrack		In & crosstrack
Pointing - in track / cross track	±30° ±30°		±30° ±30°		±45° ±45°		±45° ±45°		±45° ±45°
Sensor position	GPS		GPS		GPS		GPS		GPS
Sensor attitude	No		Star Trackers		Star Trackers		3 Star Trackers		Star Trackers
Accuracy with GCP's = / w/o GCP's =	Horiz Vert 6m 4m - -		Horiz Vert 2m 3m - -		Horiz Vert 2m 3m 12m 8m		Horiz Vert 2m 3m 12m 8m		Horiz Vert 2m 3m 12m 8m

Table 5. High Resolution Commercial Earth Observing Satellites
- Sensor Information -

TBD = To be determined
TBA = To be announced

Corporation "System"	EarthWatch "EarlyBird"	EarthWatch "QuickBird"	Orbital Sciences "OrbView-1"	Space Imaging	GDE
Altitude (km)	475	470	460	680	743
Inclination (deg)	97.3° sun synchronous	52° sun synchronous	97.25° sun synchronous	98.1° sun synchronous	98.8° sun synchronous
Repeat Cycle	20 day (max)	20 day (max)	16 day (max)	14 day (max)	16 day
Revisits Cycle	1.5-2.5 da (max)	1.5-2.5 day(max)	< 3 day (max)	1-3 day (max)	1-3 day (max)
Period (rev/da)	16	15.3	15.5	14.6	14.4

Table 6. High Resolution Commercial Earth Observing Satellites
- Orbit Information -

Corporation "System"	EarthWatch "EarlyBird"	EarthWatch "QuickBird"	Orbital Sciences "OrbView-1"	Space Imaging	GDE
Scenes (max)	500/orbit	100/orbit	535/day	process 600/day	580/day
On board recording	500 scenes	100 scenes	250 scenes,32Gb	64 Gb	60 Gb
Delivery time from Acquisition to User	15 min.- 48 hr.	15 min.- 48 hr.	15 min.- 24 hr.	24 hr.- 48 hr.	24 hr.- 48 hr.
Ground Station Sites	Colorado, Alaska, + Europe, Asia Regional Affiliates		Regional Affiliates	Denver, Alaska, Japan + Regional Affiliates	Regional Affiliates

Table 7. High Resolution Commercial Earth Observing Satellites
- Communications/Processing Information -

Partners	On-Orbit Date	Imager Type	Payload	Pixels
Agrium US Boeing Company Farmland Industries GDE Systems Pioneer Hi-Bred International Institute of Technology Development (ITD)	Late 1998 2 satellites Early 1999 2 satellites	"M10" Pushbroom	700 Kg	12 bit

GSD	Spectral Bands	Swath Width	FOV	Stereo	Pointing	Sensor Position	Sensor Attitude	Accuracy
10m	.45-.52 .53-.59 .63-.69 .76-.90	205km	15.9°	Yes in-track & cross-track	±30° in-track ±40° cross-track	GPS	Star Trackers	Without GCP- 30m With GCP- 5m absolute 1m relative
20m 100m+	1.55-1.68 1.23-1.53							

Altitude	Inclination	Revisits Cycle	Constellation Phasing	On-Board Recording
743 km	98.6° sun sync.	3.5 day @ nadir	0°, 77.14°, 180°, 257.14°	176 Gb each satellite

Table 8. Resource 21
- Commercial Earth Observing Satellite System -

TECHNICAL SUMMARY AND COMMENTS

Orbit Information

The proposed 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 plan 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. Generally, the orbits are circular, low-Earth-orbits (LEO). Orbit altitudes and tracks have been influenced by market considerations, such as optimizing repetitive coverage intervals (revisits), coverage of farming/agricultural regions, or for ground station agreements with regional and national affiliate distribution centers.

Sensor Information

Except for the two-dimensional pixel staring arrays of the EarlyBird, the sensors are all of the pushbroom type and produce 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 bands which, in general, replicate the bands of Landsat and SPOT. The 11 bit pixel depth provides high dynamic range for image manipulation and interpretation. That is, for low contrast scenes and in low lighting conditions (shadows) it will retain image quality. The Resource 21 system includes a SWIR "cirrus" band to calibrate and assist in removal of atmospheric effects. This unique, but logical, innovation of sensing atmospheric effects simultaneously with acquiring imagery has long been advocated by Dr. John MacDonald, President of MacDonald Dettwiler & Associates.

One of the remarkable characteristics of the high resolution systems is their ability to point to multiple areas of interest within very short time intervals, thus for example, enabling optimization of stereo base-height ratios or to acquire off-track stereo imaging when requested.

Communications/Processing/Marketing Information

All of the systems will rely on a store-and-forward operation to allow for ground station access and perhaps some preprocessing activities, such as data compression. To assist precision pointing to customer areas of interest the systems all use on-orbit GPS positioning.

Each of the companies has a different approach for providing imagery and imagery products to users. 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 which is metrically, spectrally, and temporally precise, and which nominally can be delivered from near-real-time to 48 hours from image acquisition! Tables 4-8 summarize the technical and operational aspects of these commercial systems. As with any new systems, it should be expected that some of these characteristics will change during development and before launch of these systems.

Market Issues

From the commercial market viewpoint it is clear that the technology has matured and the projected demand for information to support GIS, mapping, natural resource, environmental, news, Earth monitoring, etc. warrants the risk. Market projections for this industry's products consistently estimate growth to be $8 billion by the early years of the 21st century. 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.

Many have speculated whether the marketplace for imagery is sufficient to sustain multiple commercial high resolution space systems. More realistically the issue is whether sufficient capital will remain available to get the systems developed and launched, especially for the multi-satellite systems. A large outlay of capital is needed for the development to be completed before the companies can begin to realize a revenue stream. Several of the systems described in this article will cost around $500 million.

Today the infrastructure for modelling, enhancing and extracting *spatial information from digital* imaging systems is quite limited in most regions of the world. However, the years of experience from information (mostly thematic) processing of digital remote sensing data using Landsat, SPOT, AVHRR, etc. will assist the transition. As noted above, there is a rapidly growing need for temporal change data to provide information for global, regional, national and urban infrastructure activities. 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 development of efficient 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 corporate partnerships and distribution alliances, each of the companies is using different strategies, providing many consumer alternatives for value-addedimages(georegistration,orthorectification, feature enhancement, radiometric intensification, etc.) and value added products (DTM's, orthophotos, image mosaics, fused MS and pan scenes, etc.). 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 limited liability coalitions. This should not be considered a negative sign, but rather a sign 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, which has been a traditional necessity.

Institutional 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. As these commercial systems come on-line, it can be expected that the need for an international consortium may arise (Perhaps an INTEOSAT along the lines of INTELSAT). Issues and needs of common interest to the commercial operators include open skies policies, coordination of orbit allocations, pricing competition with government systems, data copyright protection, ombudsmanship to address sensitive political events, exclusivity, etc. It is quite conceivable that the growth of these commercial ventures will lead to significant commercialization of many government mapping programs.

Benefits of Commercial Digital Imaging Systems

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, temporal repetitivity, 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.

A Look into the Future

It is uncertain how many of these commercial ventures will survive in the competitive marketplace. The future is promising for many of them because of the increasing reliance of modern technological tools and social services for identification of locations and attribution of people, places and things. Digital technology is here to stay and digital imaging technology is in the forefront of automated information systems. Societal needs for information from imagery will migrate from basic mapping products to temporal, site specific updates. These data and information revisions will be requested frequently on an annual to hourly basis; in many ways the requests will be analogous to today's weather updates.

Spatial resolutions available from satellites will increase with international recognition of the benefits of all-digital imaging and processing technology. The aerial imaging industry will be transformed to digital imaging and mostly integrated with the commercial satellite companies. Many more constellations of Earth observing satellites carrying varieties of advanced sensors, from dial-a-band hyperspectral to precise pointable dial-a-scale will be launched. On-board storage and processing capabilities will permit on-satellite image comparison (change detection) and filtering so that only specified change data need be transmitted to ground processing information systems.

As we in the spatial information sciences mature and learn to integrate our technologies into the information market of the future, the burden of educating our consumers to our technology will diminish and the imagery origin of our products may well be transparent to the majority of our future sophisticated users of information from imagery. The future is very bright and promising for the photogrammetry/remote sensing/GIS community.

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