Commercial Space Imagery

With Agriculture the Next Target Area

Since my overview article on commercial high-resolution space imagery was published in GeoInformatics one-and-a-half years ago, there have been quite a number of developments in this sector. Another high-resolution satellite, QuickBird, has been launched successfully to add to IKONOS and EROS-A1. All three satellites are now fully operational, so the long-heralded competition between the commercial providers of high-resolution space imagery is at last taking place. However, this is now bringing to the fore a number of questions about the size and the viability of this particular market and about its continuity. Whatever the answers to these questions, looking to the future, interest within the commercial sector is now being focused on the potential of another rather different technology and market. On the technology side, this would involve the introduction of constellations of small satellites that can produce multi-spectral imagery, but of a rather lower ground resolution and providing wider coverage and more frequent re-visit times than those of the current high-resolution satellites. With regard to the market, the main target area for the resulting imagery would be agriculture. This possibility has been discussed for quite some time, but now circumstances have arisen where it might actually become a reality.

By Prof. Gordon Petrie

High-Resolution Space Imagery

• EROS & Ofeq

At the time of the previous article (published in the March 2001 issue), only IKONOS was fully operational, EROS-A1 having just been launched. Now the latter is fully operational, in particular with regard to its fairly complete coverage of Europe, the Middle East and the Far East. For Europe, there are now three ground stations receiving EROS imagery - two located in Kiruna and Malmo in Sweden that are being operated by the Metria Satellus organisation and the third located in Sardinia and operated by the Italian IPT telecomms company. The Middle East is covered by the main Israeli ground receiving station, while the Far East has a chain of operational stations in Korea, Japan, Taiwan and Singapore that can receive EROS imagery. Now the first North American ground receiving station - that located at Gatineau in Canada and operated by CCRS - has been signed up to receive EROS imagery. Besides which, there is a single operational ground station in South Africa. As well as EROS-A1, the long-awaited Ofeq-5 satellite (the military cousin of the EROS series) has also been launched successfully on 28th May 2002. Like the previous Ofeq-3 reconnaissance satellite, it has been placed in a highly retrograde orbit (with $i = 143.4°$) using the Israeli Shavit launcher. This compares with the near-polar orbit (with $i = 98.7°$) of the EROS-A1 satellite, which was launched from Siberia using a Russian rocket and provides world-wide coverage. The use of this particular retrograde orbit for Ofeq-5 restricts its ground coverage to the area between 36.6° latitude north and south of the Equator. However this does include the territories of all of its Arab neighbours and much of Iran.

• Market

Furthermore, since the previous article from March 2001 was published, the attempted launch of OrbView-4 on 21st September 2001 failed, while the launch of the second QuickBird on 18th October 2001 was successful. QuickBird is now fully operational, producing the highest-resolution space images - with ground pixel sizes of 0.6m pan and 2.5m multi-spectral respectively - that are available from a commercial

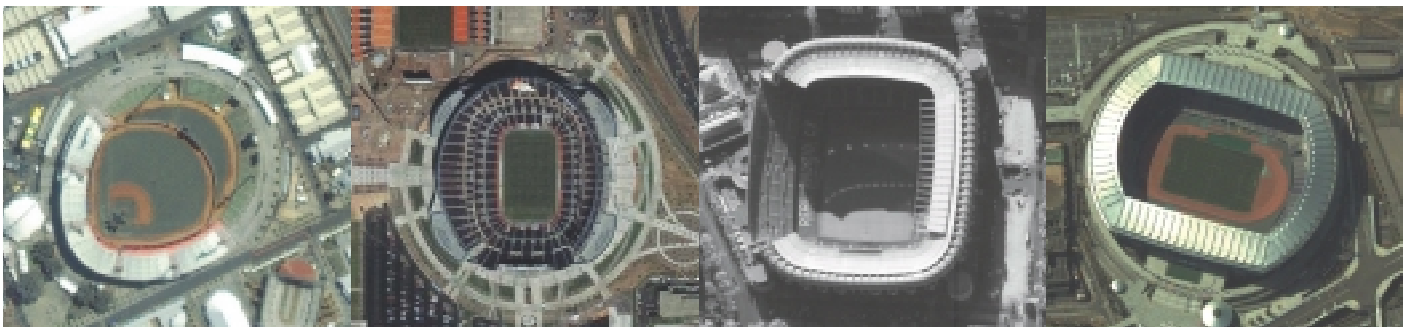


Figure 1: High-resolution space images of sports stadia acquired world-wide by the IKONOS and QuickBird satellites.
(a) Pan-sharpened image of the Olympic Park built for the 2000 Olympics held in Sydney, Australia. (Source: Space Imaging)
(b) Another pan-sharpened image of Invesco Field and Mile High Stadium, the homes of the Denver Broncos American football team. (Source: Space Imaging)
(c) Pan (60cm ground pixel) image of the Bernebeu Stadium, home of the Real Madrid football club. (Source: Digital Globe)
(d) Pan-sharpened image of the Yokohama International Stadium, venue for the final game of the 2002 FIFA World Cup. (Source: Digital Globe)

Revisited

provider of space imagery. Now that the three commercial satellites (IKONOS, EROS-A1 and QuickBird) are in successful operation, the big question is whether the respective companies are making enough money to recover the several hundred million dollars that have already been spent in getting each of them launched and operational. Closely associated with this question is whether the market is big enough to sustain all the current players in the field. To these may be added ORBIMAGE, which - having already suffered the obligatory failure of its first high-resolution satellite (OrbView-4), that all the other companies have suffered too - now hopes to launch OrbView-3 on 22nd September this year (2002) using a Pegasus rocket.

• Pricing

With regard to sales of high-resolution imagery, certainly Space Imaging received a considerable boost from the war in Afghanistan. The U.S. Dept. of Defense, via the National Imagery & Mapping Agency (NIMA), bought the exclusive rights to all IKONOS imagery of Afghanistan from 7th October 2001 onwards for two successive months for a total of nearly $4 million - plus the cost of the imagery that was actually collected at the rate of $20 per sq. km. This was described by a Space Imaging spokesman as "a wonderful business transaction for the company". According to the New York Times of 27th February 2002, NIMA paid about $8.5 million for the images and the two months of exclusive access. However, with the end of the main military operations in Afghanistan, the contract was not extended beyond 7th December 2001. On 17th December, DigitalGlobe released the first QuickBird images. Just ahead of their release, on 13th December, Space Imaging introduced a series of massive price reductions. For example, archived Geo pan (1m) products were reduced from $12 to $7 per sq. km. for areas within North America and from $35 to $20 per sq. km. for areas outside North America. The costs of newly collected Geo pan (1m) products were reduced from $35 to $25 per sq. km. outside North America. [For a minimum order of 100 sq. km, this still amounts to $3,025 for a single 11 x 11 km IKONOS scene!] Shortly afterwards, on 23rd January 2002, Space Imaging then started to offer IKONOS stereo-imagery to non-government users: previously it would only supply this type of data to government customers. Quite recently, on 9th May, DigitalGlobe reduced the cost of its basic QuickBird imagery from $30 to $22.50 per sq. km. On 3rd June, ImageSat then reduced the price of archived EROS imagery by 50% to as low as $5 per sq. km. Now Space Imaging has reduced the minimum order size for its archived Geo products of North America to 49 sq. km. This has resulted in its so-called '777' offer - coverage of an area of 7km x 7km at $7 per sq. km - which amounts to $343 for a single image. Obviously this competition between the three commercial data providers has been highly beneficial from the customers' point of view. But, needless to say, these large price cuts also cause all sorts of questions to arise - not least about the size of the present market for commercial high-resolution imagery, its profitability and its future viability.

• Profitability

In practice, it is very difficult to find any definite information about the profitability (or otherwise) of the companies providing high-resolution space imagery. In Space News of June 25th 2001, it was reported that the sales of imagery by the Space Imaging company amounted to $110 million in 2000 and were expected to reach $170 million in 2001. Obviously these figures are quite unofficial and may not be correct. Furthermore there is no indication as to the proportions of these sums that were generated by sales of IKONOS high-resolution imagery and by the lower-resolution Landsat 4/5 and IRS-1C/D imagery respectively. Whether these sums (if correct) are sufficient to pay for the substantial operational costs (including the salaries of 400 employees) and still give an adequate return on the $700 million reported by several sources to have been spent on the IKONOS satellites and the supporting infrastructure is an open question. Only time will supply the answers to these questions. In the meantime, according to Defense Daily of 1st July, 2002, intensive lobbying by the three American companies has resulted in the issue of a directive from the Director of the CIA for NIMA to make more use of commercial high-resolution space imagery for mapping purposes.

• Replacements

Given the estimated five-year life of an individual satellite and the long time (at least two to three years) needed to develop, build and launch a remote sensing

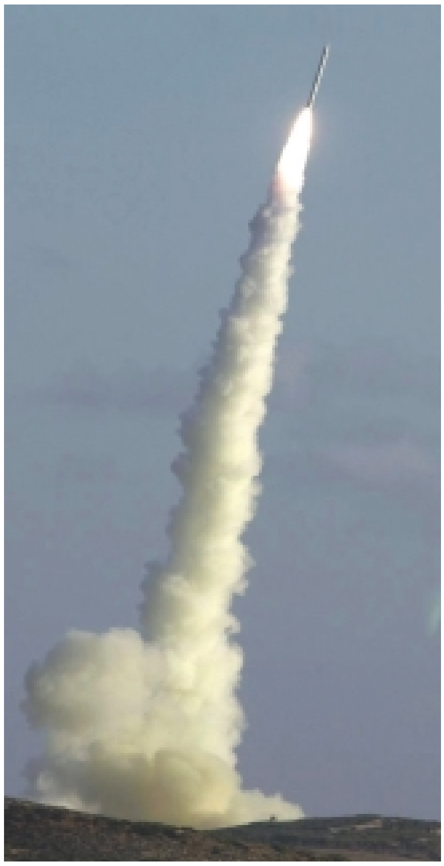


Figure 2: Launch of the Ofeq-5 satellite (Source: Israel Aircraft Industries)

satellite, it appears fairly certain that the planning for and the design of replacement high-resolution satellites must be in hand already. In this context, both Space Imaging and DigitalGlobe hold licences from the U.S. government for satellites that can produce images having a ground pixel size of 0.5m. In the case of ImageSat International, the first in its series of upgraded EROS-B satellites is scheduled to be launched in 2003. However, in a short article dated 27th December 2001, the Israeli Internet magazine, Globes, reports that ImageSat - which relies quite heavily on having international satellite operating partners who pay for having exclusive rights to the imagery that can be acquired within the footprint of a particular ground receiving station - has had trouble in finding such partners. According to Globes, so far, only Israel, Taiwan and India have shown interest in being partners for EROS-B. Still one would expect that the needs of Israel's intelligence and defence agencies will ensure that the EROS-B project will continue.

Agriculture

In the meantime, as noted in the introduction to this article, much attention is being given currently to the possibility of intro-

Figure 3: Resource21 - Overall concept and proposed markets. (Source: Resource21)

ducing another type of commercial satellite producing multi-spectral imagery of a lower ground resolution (i.e. with larger ground pixel sizes) and much greater ground coverage in a single pass. Furthermore, the projects that are under discussion all involve the use of multiple (4 to 6) small satellites to ensure frequent re-visit times and the acquisition of imagery of a given area every few days. These constellations of satellites are all targeted specifically at agriculture, though, of course, other closely related applications such as environmental monitoring are usually included in the prospectus or business plan. Farming is seen as having a large enough market for the commercial satellite operators to be able to raise the considerable investment needed for the development of this new generation of commercial satellites.

• Rationale

The rationale behind all of these projects is that the information derived from the frequently taken and fairly high-resolution multi-spectral space imagery can be used to carry out crop management and to improve fertility and crop health with a view to an increase in crop yields and profitability. This information derived from the imagery would be passed on rapidly to farmers and their advisers allowing them to decide whether to replant or irrigate their crops or to apply fertilizers, pesticides or herbicides to these crops. The information is also intended to help implement variable-rate precision farming, by which seed, fertilizers and pesticides will only be applied to specific areas as required - instead of applying them across large areas in a blanket-type operation, as apparently is often done at the present time. Also the damage caused by gales, tornados, hailstorms, flooding, etc. can be quickly assessed - which is important information for agricultural insurance companies, commodity traders and those government agencies concerned with the provision of emergency services and disaster relief.

• Ag 20/20

Underlying much of this discussion and planning activity are the large-scale programmes of research into agricultural applications of space imagery that have been undertaken in the U.S.A. As will be discussed later, initially much of this experimental work has been carried out by the commercial satellite operators (or would-be operators) planning to enter this field. However, in 1999, NASA and the U.S. Dept. of Agriculture (USDA) formed a partnership with the commodity associations representing the producers of the four largest crops - cotton, corn, soya bean and wheat - that are grown in the U.S.A. This government/private partnership, called Ag 20/20, is now conducting a further extensive programme of research and development into the utilization of airborne and spaceborne imagery by the farming community. This would allow farmers to make better decisions regarding the timing, location and extent of fertilizer, herbicide and pesticide applications and the early prediction of yield and harvest quality. The assistance of a number of American universities having specialist schools of agriculture that are experienced in remote sensing has also been sought and secured. The Ag 20/20 project started in 2001 with a target of $11 million in funding to be provided over the five years of the programme. It is now being extended to include fruit orchards and areas producing cranberries and blueberries, besides the four major crops mentioned above.

Landsat Continuity

Also forming part of the current debate in the U.S.A. is the **Landsat Data Continuity**

Mission (LDCM). As is well known, the Landsat series of satellites has been in continuous operation for 30 years providing a unique data set of medium-resolution space imagery that is invaluable for monitoring purposes. In 1992, the U.S. Congress passed the Land Remote Sensing Policy Act. This authorized the construction of Landsat-7, which was eventually launched in April 1999. Since then, Landsat-7 has been operated jointly and very successfully by NASA and the USGS. However the Act also addressed the matter of a successor to Landsat-7 to ensure the continuity of the Landsat data set. Four options were to be considered. These options were that the management and funding should be carried out either by **(i)** the private sector; **(ii)** an international consortium; **(iii)** the U.S. government (as with Landsat-7); or **(iv)** a cooperative government/private partnership. The Act made plain that Congress preferred the involvement of the private sector to keep calls on public funds to a minimum. After the successful launch of Landsat-7, NASA and the USGS started planning for its successor. From their detailed enquiries and consultations, it was soon apparent that the private sector had no interest in building and operating a Landsat-type system that would result in the production of the required medium-resolution (30m ground pixel) imagery at low cost - as desired by earth scientists and academic institutes for research purposes and by federal and state government agencies for planning and monitoring purposes.

• LDCM Proposals

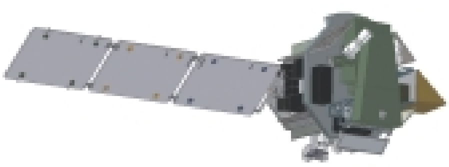
The outcome of the extensive consultation process - which included a special workshop held in Washington in January 2001 - was the proposal by NASA and USGS that they would try to ensure the desired continuity of the Landsat data set through the purchase of Landsat-type image data at the rate of 250 scenes per day from a commercial satellite operator. In this way, the two government agencies would act as "anchor customers" for a possible commercial data provider. The provider could then use the remaining capacity of the system to acquire other types of space image data that it could sell commercially. A draft Request for Proposals (RFP) to implement this scenario was issued by NASA in August 2001. It was then followed by the final RFP in November to which actual proposals had to be submitted by December 2001. In fact, NASA and the USGS did receive a number of proposals (reportedly four) from the private sector that would satisfy their requirements. In March 2002, they selected two of these proposals, from Resource21 and DigitalGlobe respectively, for further development and awarded $5 million to each of the two companies to develop their proposals further. The award to the finally selected contractor will be made in mid-2003 with the delivery of the first data being scheduled for 2005.

Satellite Constellations

It is very interesting to observe that both Resource21 and DigitalGlobe have published quite similar proposals to acquire multi-spectral images over wide areas at frequent intervals. **Resource21's** original plans date from 1996/97 and involved the launch of a constellation of four satellites acquiring multi-spectral images recorded in the visible, NIR and SWIR bands. Four of these images covering the visible and NIR region would have ground pixel sizes of 10m: the other two in the SWIR region would have ground pixel sizes of 20m and 100m respectively. The use of multiple satellites would allow short re-visit times over a given area. The newly published details of **DigitalGlobe's** proposed M5 system have many similarities to those of the Resource21 proposal. Again a constellation of four satellites is proposed that will generate multi-spectral images covering the same spectral ranges - though using the rather smaller ground pixel size of 5m. In this respect, one does note that the President and CEO of the Resource21 company till June 1998 was Herb Satterlee. He then left to take over the corresponding positions at EarthWatch (now renamed DigitalGlobe), which he still occupies. Covering the same general territory as these two American companies is the German **RapidEye** company. This proposal dates from 1998 and, from the beginning, it has had very similar objectives to those of the two American companies - especially in terms of viewing agriculture as its principal market. Again it proposes the use of four satellites, multi-spectral imagery (with a 6.5m ground pixel) and very short re-visit times. A fourth project that has been promoted since 1996/97 is GEROS. The concept has been developed by the **GER** (Geophysical & Environmental Research) **Corporation** and would involve the use of a constellation of six satellites to ensure a rapid re-visit cycle. The multi-spectral imagery would be recorded in 16 bands within the visible, NIR and SWIR spectral regions and have a 10m ground pixel size. In addition, GEROS would have dedicated pan and thermal IR (LWIR) imagers.

The respective specifications of each of these four proposals are set out in Table I (see next page). Further details of each of these four projects are given.

Figure 4:
(a) Artist's impression of the Digital Globe M5 satellite. (b) and (c) Simulation of the M5 image data in the form of (b) natural colour and (c) false-colour images for the area of a research farm used by Colorado State University. These simulated images are based on four band multi-spectral image data (with 2.8m ground pixel) acquired by the QuickBird satellite. The data were then re-sampled to produce the 5m ground pixel data. (Source: Digital Globe)



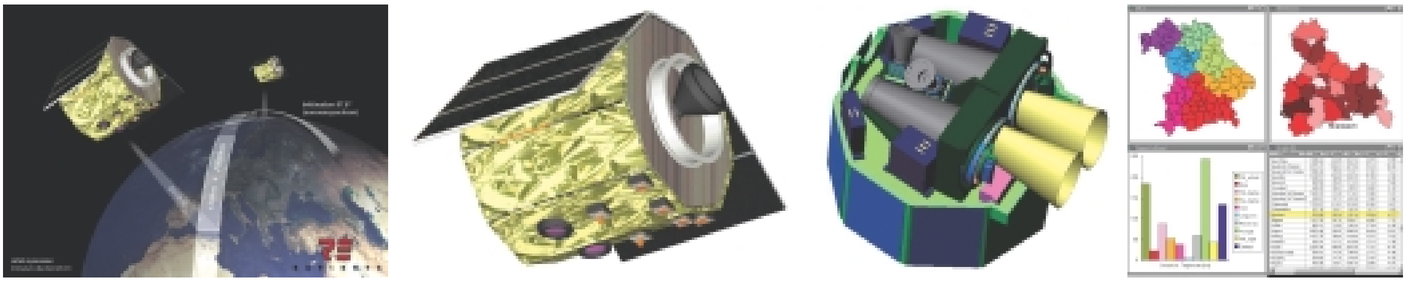


Figure 5: (a) The overall concept of the RapidEye satellite constellation. (b) Artist's impression of a RapidEye satellite to be constructed by SSTL. (c) The concept of the dual push-broom scanner imager to be built by Sira Electro-Optics. (d) The data to be delivered to customers will include crop distribution maps, graphs and tabular data. (Source: RapidEye AG)

Table I - Characteristics of Proposed Satellite Constellations

Company or Project	No. of Sats.	Orbital Height (km)	Orbital Inclin -ation	Swath Width (km)	Ground Pixel Size (m)	No. of Spectral Bands
Resource21	4	743	98.36°	??	10	6
DigitalGlobe	4	??	Nr.Polar	185	5	6
RapidEye	4	600	97.8°	158	6.5	6
GEROS	6	650	97.9°	120	10	16 + 2

• Resource21

The Resource21 project evolved out of an initiative by the Institute for Technology Development (ITD) located at NASA's Stennis Space Center in Mississippi. From 1991 onwards, ITD conducted extensive research to promote the use of remote sensing imagery for production agriculture. This was carried out using airborne imagery in close cooperation with the Agricultural Research Service (ARS) of the U.S. Dept. of Agriculture (USDA). The Resource21 company was then formed in 1995 by ITD with the backing of Boeing, GDE Systems (now BAE Systems) and Farmland Industries. Farmland is the largest farmer-owned agricultural cooperative in the U.S.A. with 660,000 members. It is engaged in extensive commercial activities, e.g. in supplying seeds, fertilizers and pesticides to farmers and in processing pork, beef and grain and selling the resulting products to customers around the world. Shortly after its formation, the Resource21 company received its licence from the U.S. government to launch four satellites. Since then, Resource21 has conducted further extensive experimental work in collaboration with the USDA and Ag Canada. Although the original hope was to launch the proposed satellites in the year 2000, in fact, progress has been slow and the construction of the satellites has not even started. Increasingly the attention of the company has been concentrated on the LDCM to provide additional backing to the project, which is still heavily focused on the provision of information to the agricultural industry.

• DigitalGlobe

This is the latest starter in the race to provide wide-area multi-spectral space images at frequent intervals. In its recent news release of 30th May 2002, DigitalGlobe mentions that it has been developing its new M5 system over the last two years in collaboration with Ball Aerospace and ITT Industries. In fact, the remote sensing interests of Ball formed a substantial component of the original EarthWatch company. Furthermore Ball has built the two QuickBird satellites, while ITT Industries has been a substantial investor in the EarthWatch/DigitalGlobe company since 1999. The news release does not mention explicitly the agricultural industry as a main target for the M5 project. However the assumption of most commentators is that it is - having noted that DigitalGlobe has formed a special agricultural business unit with an experienced team of agri-business professionals to develop its "AgroWatch" products for use in production agriculture. The vice-president of this unit is Greg Knoblauch, who formerly worked in a similar position for Resource21 between 1991 and 2000. In addition, Digital Globe has formed an alliance with the EarthScan Network, which provides rapid delivery of aerial and space imagery and derived map products to the agricultural industry. Furthermore, in January 2002, DigitalGlobe has also signed an agreement with SPOT Image to become the exclusive supplier of SPOT products and services to the U.S. agricultural (and defence) markets.

• RapidEye

In many ways, the RapidEye project parallels that of Resource21. It originated in studies that were carried out in Germany during the early 1990s. This resulted in the publication of a proposal for multiple satellites with wide swath coverage under the title Hiresat in 1993. Later, in 1998, RapidEye was formed as a joint-stock company with backing from Vereinigte Hagel Versicheung, the biggest German agricultural insurance company, and several private investors. In May 2001, RapidEye issued a statement saying that the German government will be supporting the company via a public-private partnership that will be managed by the German Aerospace Centre (DLR) within the German national space programme. Prior to this, RapidEye announced that it had come to an agreement with SSTL, the specialist builder of mini-satellites based in the U.K. This covered the supply of the planned constellation of four satellites, based on SSTL's UoSAT-12 design. The agreement also included SSTL making an equity investment in the RapidEye company. The multi-spectral imagers were to be built by Sira Electro-Optics in the U.K. Currently RapidEye plans to launch the four satellites in two pairs using Russian launchers.

• GEROS

As with most of the projects discussed above, GEROS has been proposed in the mid-1990s. Again the targeted customer base comprised the farming industry and the environmental community. Like Resource21, GER carried out a number of experimental agricultural campaigns using airborne imagers to validate its proposals. The proposed constellation of six spacecraft were to be launched in pairs. However, as with the Resouce21 and RapidEye projects, progress has been slow. GER is well known as a supplier of airborne multi-spectral and hyperspectral scanners, many of which have been used in agricultural and environmental applications. The company has also built a num-

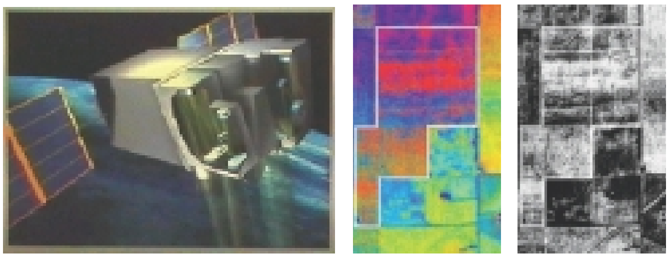


Figure 6: (a) Artist's impression of the GEROS satellite on which three different imagers will be mounted. The two nearest are the multi-spectral imagers with each covering half of the total swath width of 120km. The third and furthest imager contains both the pan and the thermal IR (LWIR) scanners
(b) The colours in this multi-spectral image represent spectral differences and can be used to discriminate between different crops and between crops and weeds
(c) The thermal image produced by the GEROS LWIR imager will generate a relative temperature map of the ground. The more heavily vegetated areas are cooler and are depicted in lighter shades of grey: the hotter areas with little vegetation are darker. (Source: GER Corporation)

ber of ground-based spectral radiometers for calibration purposes. This background is reflected in its satellite constellation proposal which features three imagers. Two of these operating side-by-side in tandem mode cover the visible and NIR parts of the spectrum in 16 bands (i.e. superspectral), while the third covers the pan and thermal IR bands. The use of the larger number of spectral bands reflects GER's long experience with its airborne multi-spectral and hyperspectral imagers. However the inclusion of thermal IR band is quite unique among the various proposals.

• Lockheed Martin
It is also worth mentioning that Lockheed Martin - which, over the last few years, has built the NOAA and DMSP series of weather satellites; the Landsat-7 and Terra satellites for NASA; and the two IKONOS satellites for Space Imaging - also submitted a proposal to NASA and USGS to implement the LDCM. Its partners in the bid were Raytheon's Santa Barbara Remote Sensing (SBRS) Lab and the Space Imaging company, in which Lockheed Martin and Raytheon hold the majority shares. Some details of the bid were given in a Lockheed Martin press release of 20th December 2001. From this, the impression was given that its LDCM proposal would utilize Lockheed's large Commercial Remote Sensing Satellite (CRSS) platform that formed the basis of the IKONOS satellites (though with different sensors for the LDCM proposal) - rather than the constellations of small satellites proposed by Resource21 and DigitalGlobe for the LDCM mission. However the Lockheed Martin/Raytheon/Space Imaging proposal was not selected and funded by NASA for further development.

Technical Considerations

• Swath Width
Although the detailed configurations of each of the satellite constellations have not been released, some of the main technical issues can be aired and discussed.
Principal among these is the matter of trying to reconcile the large swath of 185km needed for the production of individual Landsat-type images with the relatively high resolution (5 to 10m ground pixel size) of the images required for the proposed agricultural applications. This leads to the need either ((i) to use a large number of linear arrays in the focal plane of the pushbroom scanner, or (ii) to mount multiple imagers in each satellite. Of course, it would also be possible to stitch together images taken with a narrower swath from different passes over an area at different times. On the face of things, this would hardly constitute a Landsat image of the familiar type.

(i) In the case of the DigitalGlobe M5 proposal, it is possible that the use of multi-

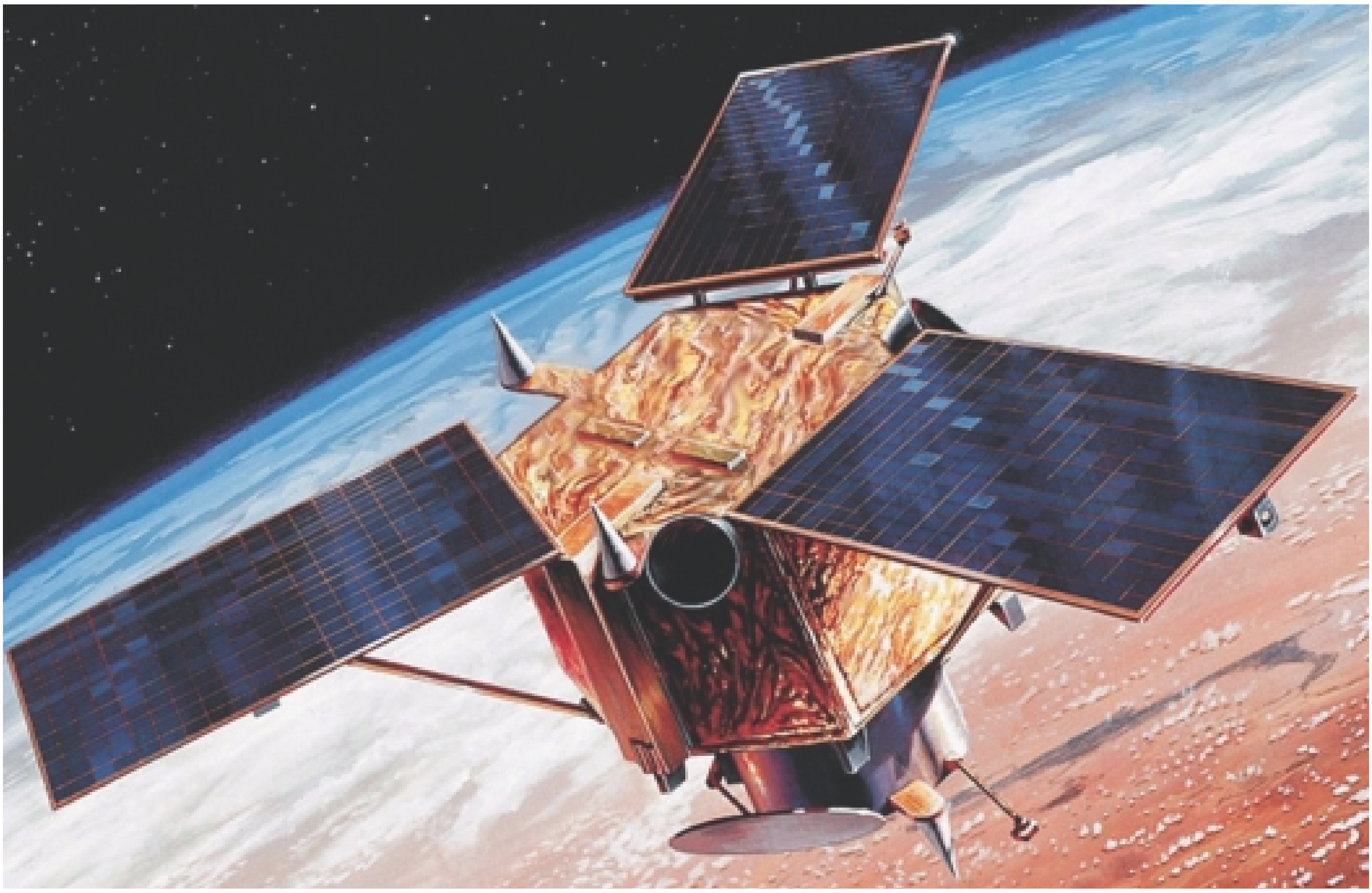


Figure 7: An artist's impression of the spacecraft proposed by Lockheed Martin for the Landsat Data Continuity Mission (LDCM), based on the company's Commercial Remote Sensing Satellite (CRSS) platform. (Source: Lockheed Martin)

ple linear arrays will have been considered - since apparently this type of solution has already been employed in the high-resolution imager mounted on the QuickBird satellite (which generates 27,000 pixels cross-track). However, for the M5 to generate an image with a 5m ground pixel size over a swath width of 185km means that the pushbroom scanner imager would need to generate 37,000 pixels per line in the cross-track direction. Since individual linear arrays of this length do not exist, one presumes that, if this solution was to be adopted, multiple linear arrays would need to be mounted in the focal plane. However, if a single wide-angle lens is used in conjunction with multiple linear arrays to produce the required wide area coverage, this places heavy demands on its resolution capabilities. Since normally there will be a considerable fall-off in the resolution of a wide-angle lens towards the edge of its field of view.

(ii) An alternative solution is to mount **multiple imagers** in the satellite. This is the solution that is being proposed by RapidEye and GEROS, neither of whom are involved in the LDCM activities. For the planned swath width of 158km that would be covered by each satellite in the RapidEye constellation, to produce images with a ground pixel size of 6.5m would require 24,000 pixels in the cross-track direction. The solution given in the papers published by RapidEye over the last year or so envisages the use of a pair of pushbroom scanners operating side-by-side. Each of the resulting imagers covers a swath of 79km with a tiny overlap between them. So the length of the linear array that has to be provided in each of the two scanners is 12,000 pixels - which is well within the current state-of-the-art in CCD linear array technology. Similarly with the GEROS project, two multi-spectral scanner imagers operating side-by-side have been proposed, with each covering 60km of the planned 120km swath width. With the 10m ground pixel size that is proposed for GEROS, this requires the final image to have 12,000 pixels in the cross-track direction. With the two imagers operating side-by-side, this should be reached quite easily.

• Ground Resolution

If, as seems likely, the two American LDCM proposals will try to combine the requirements for the 5 to 10m ground pixel sizes of the multi-spectral imagery oriented towards the agricultural applications with the 30m ground pixel size needed for the LDCM, then various alternatives can be considered. The most obvious one is simply to generate the 30m Landsat-type images from the 5 to 10m images through image processing. An alternative solution would be for each satellite to carry a separate multi-spectral imager purely for the acquisition of the lower-resolution Landsat-type data. This is possible, though very much less likely, given the duplication, complexity and cost that would be involved in implementing such a solution for multi-spectral images. If the specification for the LDCM also requires the production of pan black-and-white images having a 15m ground pixel size - as generated by the ETM+ imager on the present Landsat-7 satellite - then having a separate pan imager might well be considered. Certainly it would be easier to provide a single-channel pan imager than the multiple channels needed to generate multi-spectral images. For the Landsat ground coverage of 185km, a 15m ground pixel size requires a cross-track coverage of 12,333 pixels. There would be no problem in providing a CCD linear array of this length. Indeed, the RapidEye proposals do include a dedicated panchromatic channel on each of its imagers. GEROS would also carry a separate pan imager.

• Infrastructure

The main point about having very frequent re-visit times of two to three days - or even daily visits if the satellite is designed to be side-pointing - is to enable change detection to be carried out. Once the image data has been acquired, it will then be obligatory to carry out the processing and interpretation of the data within the shortest possible time scale. The resulting information must then be passed on immediately to the farmers, cooperatives, agricultural extension personnel and crop consultants who will be using it. Speed will be of the essence, especially if some type of remedial action such as the application of irrigation water, fertilizers or pesticides needs to be undertaken. Obviously too the necessary infrastructure must be in place for this fast delivery to be implemented. Presumably the Internet can play a big part in the rapid delivery process. Moreover a great deal of training and education will need to be undertaken with close cooperation and the sharing of experience between farmers, advisers and data producers for this whole undertaking to be effective - and especially if it is to be cost-effective. For those applications that do not need such a rapid response, the archived image products and derived data can be made available through the Internet, for example via the Digital Globe archive or, in the case of RapidEye, via the TerraMapServer based in Germany. Also less time-critical, but no less important, is the overall monitoring of crop areas, since, for example, the European Union pays its subsidies to farmers on the basis of the actual areas under crops. The new imagery could form the basis on which sample checks of the three million declarations made by European farmers could be carried out.

Conclusion

It will be most interesting to see how this particular area of space remote sensing will develop in the near future. On the one hand, quite obviously, it is an area of considerable potential. On the other hand, as the closely related field of commercial high-resolution space imagery has shown, it is also an area of considerable financial and technical risk, in which it is possible to lose large sums of money. However the time is fast approaching when decisions will have to be made as to which of the projects based on the use of constellations of small satellites mainly for agricultural applications can be funded and will be able to go ahead.

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