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Potential and Limitations of Highresolution Satellite Imagery

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Abstract

The issue of commercial highresolution satellite images has found much interest lately within the remote sensing and geoinformation communities. Performance predictions and business expectations have come close to revolutionary changes in the geoinformation industry. Several missions have been planned but only one system made it successfully into orbit. Since the costs of images are high, only few have been processed and critically investigated by the scientific community. Therefore very little experience is available so far with respect to the quality and usability of this data and the derived products.

In this paper we report about the first results obtained with IKONOS-2 images. We assess both the radiometric and geometric accuracy of this data and compare them with aerial images of similar scale. We briefly remark about road and building extraction and the pricing policy. Finally we summarize potential and limitations of this first generation of commercial highresolution satellite images.

1. Introduction

Highresolution satellite images (HRSI) at 5m and better geometrical resolution, their use and limitations have become a source of ongoing discussions since a number of years. Especially the commercial 1-4 m sensors have attracted much attention since 1995, in particular within the photogrammetric, mapping and GIS communities. Highflying expectations concerning the opening of new and hitherto untouched business markets were raised. As always in such situations of emergence of new technologies the problem of exaggeration, the danger of false predictions and unrealistic expectations are imminent. The first blow to these rosy dreams came with the failure of some of the launches. After the successful deployment of the first system (IKONOS-2) customers are still waiting for the promise of instant delivery of value-added products to be fulfilled.

There are serious and unsolved issues related to the business model of the HRSI providers, legal aspects concerning licenses and royalties, government restrictions (including shutter control), maintenance of standards and specifications from government to the geoinformation industry, unlawful use of images and derived products. On the technological side there are problems with undisclosed camera models, the accommodation of the vast amount and diversity of satellite images and products, and education and training of this business sector. Fraser, 1999 and Fritz, 1999 have addressed some of these issues in detail.

In our paper we will mainly focus on the technical aspects of HRSI, but also make some remarks to the business models.

As of today very few concrete results of tests of processed images from the 1-4 m range are available and speculations concerning the potential and limitations of these images are still widespread.

We will start with a survey of planned highresolution satellite missions for the next 3 years. Then we will briefly compare system and performance parameters of space and aerial systems. Another issue of concern will be the image quality of HRSI data, in particular some aspects of geometrical resolution, both in terms of theoretical considerations and evidence from practical results. This paper will report about some first results obtained with IKONOS-2 CARTERRA images over an

area in Switzerland. We will also refer to the radiometric quality of the images. Concerning the generation of orthoimages we will compare different modeling approaches for differential rectification, which will also allow us to assess the metric accuracy performance. These results are essentially taken from a recent publication in German (Kersten et al., 2000).
We discuss the possibility of road extraction from these images, using our semi-automated procedure of LSB-Snakes and comment on the extraction of buildings and the generation of data for 3D city modeling.
Comparing these results with data obtained from small scale aerial images will hopefully help to attain a more realistic attitude towards the potential and limitations of highresolution space imagery.

2. Highresolution earth observation satellite launches 2000-2004

As evidenced by the information on the worldwide launch forecast of satellites (www.flatoday.com/space/next/sked.htm), planned earth observation activities are manifold during the next few years. Among those are many highresolution missions, which are collected in Table 1.

Table 1: Highres earth observation satellite launches 2000-2004

Date	Spacecraft	Launcher	Country/Remarks	Best resolution
12 Mar 2000	MTI	Taurus (T5)	USA, MS thermal imager	5 m VNIR, 20 m TIR
28 June 2000	Tsinghua-1	Cosmos-3M	Tsinghua Univ., Beijing, microsat, Highres imaging	?
1 Sep 2000	Ziyuan-2	CZ-4B	China/Brasil	5 m
29 Sep 2000	Kometa-20		Russia, KVR-1000 camera	2 m
21 Nov 2000	NMP/EO-1	Delta-7320	USA, NASA	10 m PAN, 30m MS HS 220 bands (30m)
21 Nov 2000	QuickBird-1	Cosmos-3M	USA, EarthWatch Inc.	0.8 m
end Nov 2000	EROS-A1	Start1, Russia	USA/Israel, based on Ofeq-3	1.5 m
early 2001	IRS-P5	PLSV, India	India/defense	1 m
14 April 2001	Orbview-4	Taurus (T6)	USA, Orbital Sciences	1 m, HS 280 bands
Q3 2001	Orbview-3	Pegasus-XL	USA commercial	1 m
Q3 2001	EROS-A2		USA/Israel	1 m
Q3 2002	IRS-P5		India, Cartosat-1	2.5 m stereo
2001	IRS-P6		India, Resourcesat	5.8 m pan, 23 m
Q1 2002	EagleEye		Germany, based on UoSat-12	5-7 m
2002	Radarsat 2		Canada	3 m radar
2002	CBERS-3		China/Brasil	3 m
2002	CBERS-4		China/Brasil	3 m
2002	ALOS		Japan	2.5 m
2002	SPOT-5		France	5 m
2002	ROCSAT-2		Taiwan, land & ocean	? m
2003	IRS-2A		India, Cartosat-2	1 m
2004	Resource21		USA commercial	10 m
2004	TerraSAR		DLR, Radar	1 m

At the time of the writing of this paper (November 2000) we receive the report that another commercial HR mission (launch of Quickbird-1 of EarthWatch Inc. on 21 November 2000) has failed. This puts the successrate of HR commercial launch missions to 1 out of 4, or in other words, considering Table 2 (Proposed Commercial Launches) in Fritz, 1999, out of 11 planned missions up to and including the year 2000 only a single one made it - a fairly depressing story.
On the other hand, out of the 16 HR missions planned within the next 4 years we hopefully can expect many to succeed. Then the skies will be loaded with systems and sensors providing a stream of high quality data never experienced before in history. Are we ready to cope with this flood of information? Is the methodology and software for information extraction ready for use and efficient in order to be able to make good use of these treasures? What kind of information can we extract from these images and at what accuracy level? What is the role left for aerial photogrammetry to be played, especially considering the new highresolution digital cameras? What will the business models of the providers be and how will the prices develop, given the tough competitive situation.
There are many questions to be addressed in the months to come and we are looking forward to a most interesting period for those who are active in the scientific, development and business domains of the geoinformation industry.
Amidst the hype about the HR digital space images a note must be made on the Russian film-based sensors which have been around and are available for a number of years.
Images are available from the cameras listed in Table 2.

Table 2: Highresolution Russian film-based images

Camera	„Footprint“ [m]	Film	Format [cm^2]	Ground coverage [km^2]	Stereo coverage [%]
KATE-200	20	spectrozonal	30 x 30	243 x 243	60
TK-350	10	PAN	30 x 45	200 x 300	80
MK-4	6-8	spectrozonal	18 x 18	117 x 117	60
KFA-1000	5	spectrozonal	30 x 30	80 x 80	60
KFA-3000	2-3	PAN	30 x 30	30 x 30	N.A.
KVR-1000	2	PAN	18 x 82	40 x 180	N.A.

N.A. ... not applicable

On 29 September 2000 the KOMETA-2 satellite has been launched successfully. Images are available since 13 November 2000. KOMETA-2 carries a TK-350 camera (10 m footprint), producing stereo coverage, as well as the KVR-1000 (2 m footprint). The KVR-1000 is a panoramic imager, with a camera model similar to NASA’s KA-92.

3. Comparison of space and aerial systems

While both systems might complement each other in some applications, they are competitors in others. Therefore it is useful to shed some light onto both concepts by comparing relevant performance parameters. We will compare IKONOS-2 imagery, old and new photographic aerial cameras, digitized (scanned) aerial images, and the series model of the digital camera ADS40. „New aerial cameras“ means with forward motion compensation and possibly a new generation of films, like the Kodak AEROCOLOR III Negative Film 2444 (compare Brake, Mango, 2000).

For technical details on the ADS40 see for instance Sandau et al., 2000.
Table 3 compares some of relevant parameters of the four systems, based on the nominal image scale 1:68 000.

Table 3: Comparison of space and aerial system parameters (nominal image scale1:68 000)

Camera systems	**Flying height [km]**	**Resolution/ footprint [m]**	**Ground coverage [km^2]**	**Field of view [°]**	**Number of pixels**	**Spectral range PAN**
IKONOS-2	680	1	11 x 11	0.93	11 000	0.45-0.90
Filmcamera old [1] new	10.2	0.50 [3] 0.25	15.6 x 15.6	75	-	0.35-0.70
Scanned aerial image [2]	10.2	0.68	15.6 x 15.6	75	23 000	0.35-0.70
Digital camera ADS40	4.2	0.22	5.3 x 5.3	64	20-24000	0.46-0.68

1) With camera constant c = 150 mm
2) Scanning with pixelsize 10 µm
3) Resolution old camera system: 50 lp/mm
Resolution new camera system: 100 lp/mm

The numbers of Table 3 show that, at the same nominal image scale, the aerial images cover a larger ground area and, together with their superior geometrical resolution, contain much more information. For the future, space images and images from digital aerial cameras are competing with each other in a more direct fashion. Then the considerations of Table 4 may also become important.
Obviously, digital aerial cameras have a number of substantial advantages.

Table 4 : Comparison of satellite sensors with digital airborne systems

Satellite sensors	**Aerial systems (digital)**
+ Fixed trajectory at constant height + Availability depends on weather + Full atmospheric MTF + Fixed geometrical resolution 1 m PAN 4 m MS + Stereo partners at request and extra cost	+ Flight pattern on demand + Partially dependent on weather (flight beneath clouds possible) + Partial atmospheric MTF + Footprint adaptive 0.05 – 1 m PAN 0.1 – 2 m MS + Stereo partners included (ADS40 actually has 3- fold coverage)

4. Image quality of HRSI data

Within the chain from image sensing to the final value-added product the quality of the images obviously plays a pivotal role. No product can be better than the primary data.
Image quality is defined by the following parameters:

(a) Geometrical resolution and contrast. This is described by the Contrast- and Modular Transfer Function (MTF), or in more general terms by the Optical Transfer Function (OTF), including also the phase information of the recorded signal.

(b) Sensor model (geometry of projection). The quality of the established sensor model describes the difference between the „true“ model (which is essentially inaccessible) and the chosen approximation, in terms of type and size of systematic errors.
The recovery of the sensor model is of key importance in case it is not released for a particular sensor by the provider. Self-calibration can play a central role in such a procedure.

(c) Radiometric resolution and its accuracy. This is represented by the signal-to-noise ratio S/N.

(d) Spectral resolution. This is described by the number of spectral channels available and the sensitivity of the sensor within each of them.

A thorough analysis of a system must address all these parameters. Up to this point in time there is very little experimental data available from HRSI of the 1-4 m range. Zhou, Li, 2000 have done a simulation study for IKONOS–2 data, assuming different ground control point (GCP) distributions and computing the associated accuracies for point positioning.
Since reference is made to IKONOS-2 data in the sequel we give some important parameters of the mission and sensor, which are not all readily available from the published literature:

+ Flying height above ground: 680 km
+ Camera constant c = 10 m
+ Nominal image scale 1: 68 000
+ Physical pixel size: 12 µm
+ Footprint in PAN (0.42-0.90) mode: 0.82 m, in MS mode: 3.28 m
+ Number of available pixels in CCD line: 13 500
+ Swath width at nadir: 11 km
+ Nominal scene size: 121 km^2
+ Field of view: 0.93°
+ Stereo: In & crosstrack
+ Single camera, works in tilting mode to generate the fore/after and acrosstrack images with viewing angles up to +- 45° each
+ Repeat cycle: 14 days max.
+ Revisit cycle: 1-3 days
+ Period: 14.6 revolutions/day
+ Expected accuracy: With GCPs: σxy = 2 m, σz = 3 m
Without GCPs: σxy = 12 m, σz = 10 m

The author has received a personal note from C. Fraser, University of Melbourne, Australia, who reported about first empirical metric accuracy tests with a IKONOS-2 stereo pair (nadir&back) in a 6*7 km area of Melbourne. The resulting RMS error from 60 checkpoints is at the 0.5 m (or 0.5 pixel) level, which hints at an excellent metric quality of the IKINOS-2 images.
The planimetric accuracy in point positioning of signalized points with aerial film-based cameras is at the 2 µm level, given a block with 60% image overlap in both directions. If we assume a resolution of the optical system of 50 lp/mm, these 2 µm correspond to 1/5 of the width of a line in image space.
Comparing the resolution of optical (film-based) sensors with electro-optical sensors one has to take into account the Kell factor (a value of 2.7), which must be used to correctly transfer the resolution of one sensor type into the other. Thus we get the following relation:

Width of a linepair (resolution of film-based) = 2.7 * Pixel size (resolution of electro-optical)

A film camera resolution of 50 lp/mm would then translate into a pixel size of 7.4 µm (and not into 10 µm, as often wrongly assumed). With the practical example given before (0.5 pixels for IKONOS-2) the corresponding accuracy for the film-based system would be 3.7 µm, hence not as good as the actual value. In other words, IKONOS results must deliver an accuracy of ¼ of a pixel in order to match the accuracy of a film-based system.
This is in accordance with another computational approach. Given a camera constant of IKONOS-2 of c = 10 m and a flying height of 680 km we obtain a nominal „image scale" of 1:68 000.
An aerial image of the same scale and 50 lp/mm resolution will result in a footprint of 0.5 m.
One may even argue that modern aerial cameras with forward motion compensation will have an area weighted average resolution approaching 100 lp/mm, resulting in 0.25 m footprint.
This consideration however is a bit hypothetical and does not consider the severe geometrical differences in both approaches. With the film camera we have fourfold image overlap for most of the points (with a maximum of ninefold), while in case of IKONOS-2 we have only two images. On the other hand the aerial image covers a area of about 27K by 27K pixels, while in the case of IKONOS-2 the used image size is only 6K by 7K pixels.
Also, we see some significant progress in colour film manufacturing. According to Brake, Mango, 2000 Kodak has developed and brought to the market a new colour film for aerial cameras: AEROCOLOR III Negative Film 2444. With its new T-GRAIN emulsion it is faster, of better image quality and with wider exposure latitude than existing films. At average lighting conditions it works at 1/750 sec with an aperture setting of f/5.6. The resolving power is specified to 80 lp/mm at TOC 1.6:1 and 125 lp/mm at TOC 1000:1. An ultraviolet filter, built into the film, reduces the effects of atmospheric haze and thus improves sharpness. It provides for a higher dynamic range, giving more details in shadows and light-saturated areas.

Further tests must give us more representative answers to the questions of radiometric and metric accuracy and integrity of the new sensors.

5. Tests with IKONOS-2 CARTERRA images

The results reported in the following are a brief excerpt of the investigations in Kersten et al., 2000, with acknowledgement of the excellent work of the authors.

Data set
The IKONOS-2 images (PAN and MSI GEO products) over an area around the town of Zug, Central Switzerland were ordered for the period of 25.2. to 10.3. 2000. The images (4 PAN 1 m and 3 MSI 4 m) were acquired on the 25.3. and 8.4. 2000 and delivered on the 16.4. 2000. So much to the problem of timing and instant delivery. Figure 1 shows a portion of the MSI GEO image. The accuracy of the image points is specified to 50 m circular error at 90% probability, or 23.6 m RMS error. These values do not include errors induced by the terrain relief. Height differences amount to 600 m in the area.
For comparison a digital colour orthoimage from the project Swissphoto Orthophotos DOP75 with 0.75 m pixelsize, derived from aerial images 1:27 000, flight summer 1995, was used. The estimated accuracy, which is limited by the quality of the underlying national DTM (DHM25), is 1-3 m. For geometrical accuracy tests orthoimages with 0.25 m pixelsize, generated from aerial images 1:5 000, with an accuracy of 0.25 m, were used.

Figure 1: Portion of an IKONOS-2 GEO MS image (4 m pixel) over Zug, Central Switzerland

5.1 Radiometric investigation

Figure 2 shows a patch of the IKONOS GEO PAN image (1 m pixel), in comparison with the respective patch of the orthoimage (0.75 m pixel). The big difference in radiometry is due to the facts that (a) IKONOS PAN extents its spectral range into the near IR region (0.45 µm - 0.90 µm), while the aerial image cuts off at 0.70 µm and (b) that there is a distinct difference in time of image acquisition (April 2000 against summer 1995). The IKONOS image is also more corrupted by noise. This becomes evident with Figure 3, which shows the noise pattern of the IKONOS PAN image. We recognize a checkerboard noise pattern and a wrongly calibrated pixel, generating a distinct line in the image. Such stripes exist in several parts of the image and run over the whole image format.

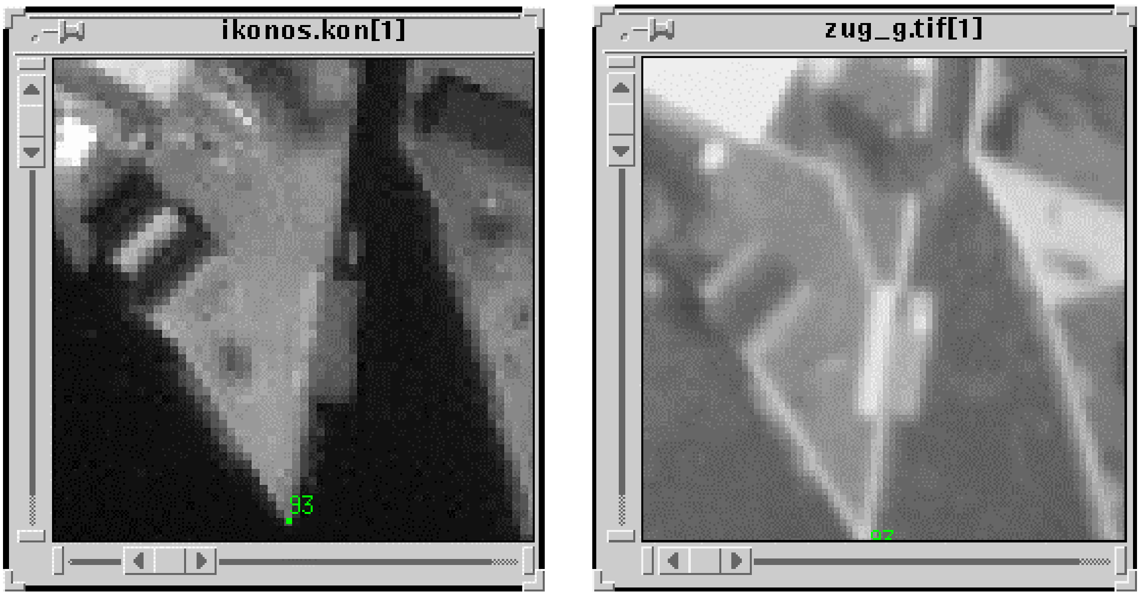

Figure 2: Differences in resolution and noise level between satellite GEO image and aerial ortho
Left: IKONOS GEO PAN (1 m)
Right: Aerial orthoimage (0.75 m)

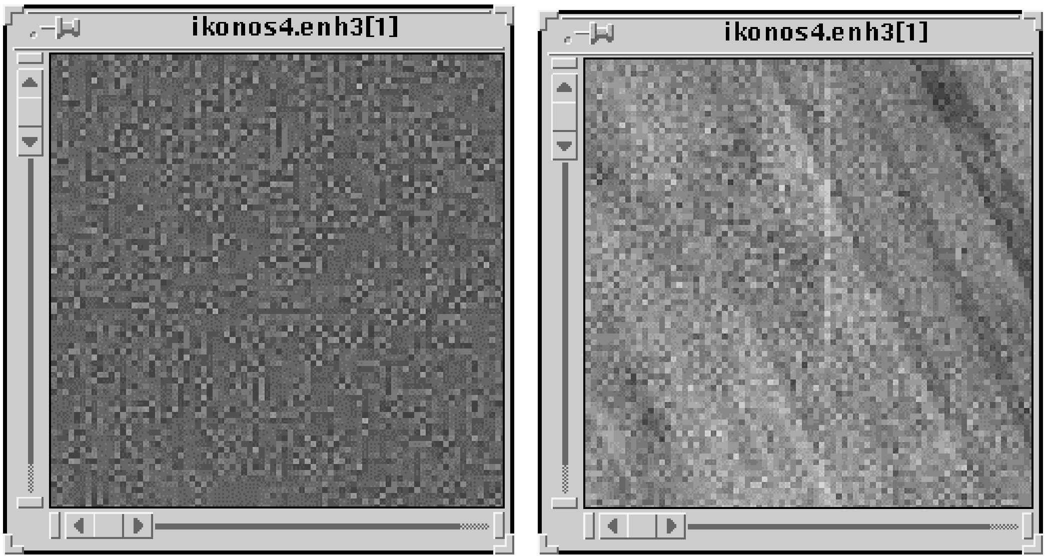

Figure 3 : IKONOS PAN after contrast enhancement
Left: Checkerboard noise over lake Zug image patch
Right: Checkerboard noise plus vertical line over field image

5.2 Geometric processing

The metric quality tests are based on 3 different geometrical processing algorithms for single images:

(a) Geocoding by coordinate transformation
This method uses the metadata information in order to transform the image from the given UTM into the projection of the Swiss National Coordinate System (SLK)

(b) Orthoimage generation with Kratky's polynomial mapping functions (Kratky, 1989)

(c) Geocoding with empirical orthorectification
This method is an approximation of the strict differential rectification.
It is based on an affine transformation (6 parameters) of the whole image under consideration of the relief displacements, computed from the underlying DTM. The relief displacement correction is applied to each control point which goes into the computation of the transformation parameters and to each image pixel for differential rectification.

Only methods (b) and (c) need control points, which were taken from the orthoimages DOP75.
For the matching of the control point image patches between DOP75 and IKONOS-2 semi-automated LS Matching was applied. In order to be able to cope with the big differences in radiometry (compare Figure 4) the gradient images of the patches were used for matching instead of the original greyvalues. This has proven to be a useful approach when dealing with multitemporal SPOT images (Baltsavias, Stallmann, 1993).
The evaluation of the results of these different methods for geocoding and differential rectification is based on 65 well distributed checkpoints, which were taken from the orthoimages DOP75.
For the detailled record of results of the accuracy study we refer to Kersten et al., 2000. The key results are shown in Table 5. The DOP75 results are obtained by comparing the checkpoints with those from the 0.25 m pixelsize orthoimages.

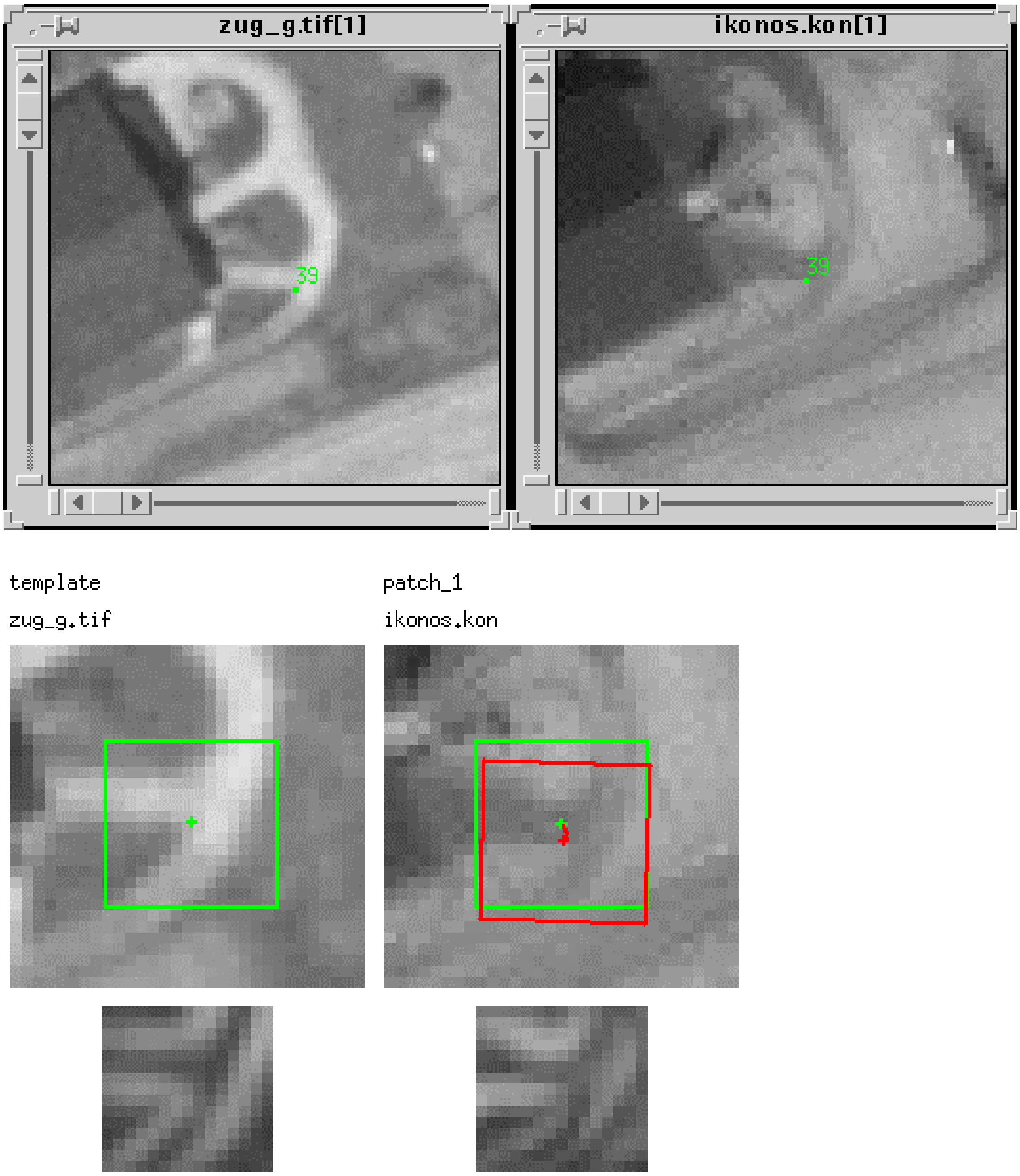

Figure 4: Control point measurement using LS Matching with gradient image patches
Left: Aerial orthoimage (0.75m)
Right: IKONOS GEOPAN (1m)

Table 5: Results of accuracy tests of different methods of geocoding

	Method (a)		Method (b)	Method (c)		DOP75
	PAN	MSI	PAN	PAN	MSI	
RMS XY [m]	7.2	10.6	1.6	2.2	1.6	2.0

As expected, method (a) delivers fairly inaccurate results, due to the fact that the height differences in the DTM are not considered. Since the terrain heights cover a range of 395 – 990 m, an error component in the order of a few meters can be expected.
Surprisingly, method (c) delivers a better accuracy with the 4 m MS than with the 1 m PAN images. This can probably be explained by the fact that the DOP75 data at 2 m accuracy is not good enough to serve as reference data and thus the reliability of the computed RMS errors are rather low.
Therefore the accuray potential of the derived orthos could not fully be tested with this data. However, even then the accuracy of the differentially rectified satellite orthos is surprisingly high. It is in the range of the much more expensive PRECISION products. This confirms that even without release of the camera model a very high accuracy can be obtained by correct differential rectification. This is in good agreement with the first test results of C. Fraser (personal communications, November 2000). Hence it can be assumed that one pixel or even subpixel accuracy is possible for well-defined point and line features, even with the GEO images.

6. Semi-automated extraction of roads and buildings

Roads
We have tested the IKONOS-2 PAN image over Chur for its suitability for road centerline extraction. Using our semi-automated technique of LSB-Snakes we made similar experiences as with small scale aerial images (Gruen, Li, 1997). A key to success is the radiometric road model used. With larger image scales these models become more complex and the performance of the extraction algorithms decreases.
Our radiometric model was designed for medium resolution space images (SPOT 10 m) and showed very good performance there. At the 1 m pixel level we encounter some problems, which need more R&D efforts to be solved.
If a DTM of sufficient quality exists road extraction by monoplotting in semi-automated mode could be an interesting option.

Buildings
The suitability of HRSI for building extraction and 3-D city modeling depends on the required level of detail and accuracy of the models. Today we see in this area many applications with varying requirements (from monument preservation with very high requirements in terms of resolution and accuracy to telecommunications with less stringent ones). In general, the trend is clearly (and this holds for all applications) towards higher level of detail, in many cases with object details smaller than 0.5 m at an accuracy of 10 cm requested.
Therefore we cannot see a great future in extracting buildings from 1m pixel images.

7. Pricing policy

Since the business and pricing policy also determine the potential and the limitations of a system and its image products we would like to refer to Fraser, 1999 for some critical comments on that issue.
According to Harris, 2000 we can distinguish the following pricing policy options (compare also www.geog.ucl.ac.uk/eopole):
+ Free data for all users
+ Marginal cost price for all users
+ Market driven, realistic prices for all users
+ Full cost pricing
+ Two tier pricing
+ Access key pricing

+ Information content pricing

Pricing policy in the HRSI market is still very much under discussion. A very simple solution would be to leave it up to the market for self-regulation with respect to supply and demand.
While this may be justified for purely commercial markets we have to consider the fact that a majority of projects in satellite remote sensing is still driven by subsidized financial structures and others are integral services to the society and regional and local communities.
Other interesting aspects arise with the Internet opportunities. Harris, 2000 lists several options which could be followed by using the Internet to selling earth observation data:

+ Earth observation data is offered free of charge, while the supplier generates revenue from the advertisers who use the web site
+ On-line services deliver only the data the user really needs. Sub-regions of an area can be specified and parts of the data can be ordered and delivered over the web
+ Data is auctioned over the web. If linked to satellite programming the auction would be for the data rights rather than for the data per se. Inverse auctioning could be envisioned when a user posts on the web a data requirement and suppliers are offering their products on a competition basis.

In Switzerland digital colour orthoimages are available from Swissphoto AG with 0.625 m pixelsize, 24 bit, with an accuracy of 1-3 m in flat and hilly terrain and 3-8 m in the mountains. Depending on the amount of data ordered the prices vary currently between US$ 6.3 - 38.1 per km^2. This compares to IKONOS-2 prices of US$ 59-99 for 1 m PAN (B&W) and US$ 68 - 114 for 1m PSM (PAN-Sharpened Multispectral). Obviously Swissphoto AG products come with higher resolution at a substantially lower price. In addition, the company gives significant educational institution discounts.
The IKONOS-2 prices refer to standard products. The restrictions for those products are actually drastic and include:

+ Minimum image dimension must be 11 km on each side
+ Minimum purchase price is US$ 3 000.-
+ Order must be a contiguous area
+ Requests for cloud-free data better than 80% are quoted on a case-by-case basis
+ International orders may require customer supported GCPs & DTM

8. Potential and limitations

Since the suitability and limitations of HRSI depend on the particular applications, it is difficult to come up with some general statements which could be valid for all cases. Nevertheless, one can formulate a number of aspects which might be helpful for the evaluation of these images in general terms. Here one should always keep in mind the alternatives offered today and in the near future by aerial platforms, e.g. high altitude aerial photographic cameras, digital cameras, MS scanners, laser scanners and radar systems.

Frequent coverage
The revisit cycle for IKONOS-2 is 1-3 days. This sounds exciting at first sight, but in many countries the weather (clouds, rain, fog, etc.), time of the year or time of the day will have a severe impact and may prevent the acquisition of good imagery when it is needed.

Instant availability
This is indeed an intriguing aspect, but it remains to be seen whether space images can be made available faster than aerial digital images.

High geometrical resolution
Here aerial images, because of their flexibility in image scale, do have a distinct advantage.

High metric accuracy
The metric accuracy of the images used in our test is surprisingly high. By applying sufficiently strict orientation and differential rectification techniques one can produce orthoimages in the one pixel or even subpixel range by using the least expensive GEO product.

Availability of PAN and MS
This is not a unique feature of HRSI. Colour and IR aerial images are increasingly becoming available and so are MS scanners from aerial platforms. In addition, the new digital cameras will also have MS capabilities.

Value added products
The supplier's policy of delivering only value-added products and withholding the camera model is highly questionable and may turn out to be contraproductive for the business as a whole.
For a photogrammetric expert it will not be difficult to either decipher or circumvent the camera model anyway. Here the history of GPS should have told us a lesson.

Generation of orthoimages
Nadir images with their small field of view (0.93°) are excellent candidates for orthoimage generation. Only very large errors in the DTM will influence the geometry of the product (the maximum radial displacements caused by errors in the DTM are only 0.8 % of the height error, i.e. 0.8 m in case of 100 m height error). As the sensor is tilted these errors will increase linearly with the distance of the point under consideration from the nadir point.

Derivation of vector maps
While orthomaps are a very appropriate product, some reservations must be voiced when vector maps at medium or large scales are to be derived.
Dial, 2000 remarks that IKONOS has already demonstrated the capability for mapping at 1:50 000 without ground control and 1:4 800 with ground control. While this may be correct for the 1:50 000 case both in terms of point positioning accuracy and (to a lesser extent) of image resolution it is not feasible for 1:4 800. The latter case would require a positional accuracy of about 4 m for all objects. According to the US National Map Accuracy Standards (NMAS), the horizontal errors on maps larger than 1:12 000 should be not more than 1/30 inch (0.85 mm) measured on the publication scale. This seems to be feasible for the great majority of cartographically relevant objects. The problem however is with image interpretation. The footprint of 1 m does not allow us to resolve and recognize all the small objects that are required at 1:5 000 scale. Also, maps at this scale, at least in Europe, have a height contour interval of 2.5 m. The height accuracy of IKONOS data does not give this interval at a statistically relevant level of significance. Therefore, only with great sacrifices in map standards could we derive a map 1:5000 from 1 m pixel images.

Quality of products
There are no rules and procedures for quality assurance available yet. Warranty regulations for below-standard value-added products do not exist.

Pricing and costs
This is an open issue. The current prices for HRSI data don't seem to be at a level which could promote the geoinformation market. Market mechanisms together with possible government subsidies will ultimately dictate the prices.

New market niches
The highly advertised new markets have not materialized yet. Quite contrary, we note that many new applications like 3-D city and environmental modeling for visualization, simulation and animation are aiming at much larger image scales. As the measurement of the digital Earth progresses, the quest for geoinformation at very high resolution level is gaining in importance.

9. Conclusions

Many issues surrounding the generation, processing and marketing of highresolution satellite images, in particular as far as the commercial domain is concerned, are still under discussion.
We have emphasized in this paper that high altitude aerial images, especially when they are produced by the new digital cameras, are a viable alternative. Besides the technical and pricing policy issues presented here other relevant questions arise: Are the user communities prepared to handle this new form of geoinformation? Can they deal with stereo- and multi-image arrangements and oblique coverage? How are images and derived products validated? Can quality assurance procedures be developed and will this lead to a product warranty for the protection of the customer? Where are the methods, systems and software to process the images automatically in a reliable fashion? The techniques of automated 3-D object extraction are still operating at a very rudimentary level and even the DTM generation task by image matching is not solved yet.
Therefore, since black-box processing systems do not exist, who will educate and train the many to-be-expected non-expert users? Do they want to get educated in the technicalities of photogrammetry and computer vision in the first place?
Also, very little experience is available with respect to dataflow issues, archiving and retrieval of images and products in production environments.
Does commercialization of satellite remote sensing have a future? What scenario will evolve in the years to come? Will some government agencies continue to put subsidized images and products on the market, as they did it in the past and do it currently and thus compete with private business? This is a serious and contentious issue as both parties are entering the same market segment, both in the metric (< 5 m) and spectral domains.
What will be the role of medium resolution satellite sensors?
Despite all these open questions we can expect highresolution satellite sensors, together with new generations of airborne digital cameras, MS scanners, laser scanners and radar systems to become key components of the emerging worldwide geospatial information community.

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