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CRITICAL REVIEW OF THE STATUS OF REMOTE SENSING

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1. Introduction

The following series of statements on the current status of Remote Sensing and the outlook for the near future are more subjective than one expects to find in scientific papers. Making certain points clear to an outsider's audience calls for a fair amount of simplification, some exaggeration, and even a bit provocation.

I myself have during the past years been under influence of these advertising techniques, when working as a physicist in an international educational institute, and became strongly interested in realistic applications of the unconventional aerospace surveyance tools.

Questions from students and visitors, from colleagues and officials about the prospects of remote sensing already contain a good deal of simplification and exaggeration; this may partly be the reason they have provoked the current ideas. For instance:

"Which remote sensing technique should preferably be used in a satellite instead of in an aircraft?" (Minister for Science Policy, the Netherlands);

"For whom has remote sensing been developed; is it also available for us?" (An ITC student from an African country during a lecture);

"It often seems that remote sensing people want to take all information needed from the RS records; don't they know anything a priori or by using already available data and relationships?" (A professor in Photogrammetry, FRG).

"To what extent will remote sensing be operational in the near future in the LDC's (low developing countries); how many students can we expect for training in the applications of RS imagery?" (A colleague at ITC).

The last question can be answered only if the other problems have been analysed; this gives a good argument to start with a discussion of the prospects of the big three remote sensing techniques and aerial photography.

2. From Aerial Photography (AP) to Orbital Photography (OP)

2.1 Aerial Photography

Excellent geometry for planimetry, height, area, slopes, etc.
Object contrast versus surround is mainly used; not intensity (density) as such.
Very large scales possible (1:1000); small scales down to 1:100 000 feasible.
Availability of theory, instrumentation, education, methodology, cost-benefit know-how. Bulk of work in the large scales; Glamour (research & theory) in the small scales. Application possible in almost all countries of the world.
Limitations: No repetitve coverage within a year, nonuniform and uncalibrated intensity measurements obstruct automatic density processing. Small scales expensive.

2.2 Lear-Tek Photography - LTP:

Hyperaltitude aerial photography with modern systems approach: Breakthrough! Balanced set of Vehicle (Lear-Jet: 18 km), Camera (Itek: 21 cm), Processing Equipment. Powerful acquisition capacity (10^4 km^2/hour); supra national aspects; leasing (?). Emphasis on geometry, speed of small scale mapping, automation (normal angle). Fills from 1978 onwards a gap between air and space, between plane and planet.

2.3 Rocket Photography

Example: Skylark = a British Blunder

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2.4 Orbital Photography - OP:

Examples Gemini, Apollo, Skylab, Soyuz, soon Spacelab.
Has been stimulating, hardly useful; no future, not even for research! Too high for useful geometry and too late (Spacelab versus LTP). Too scanty and irregular for useful coverage; repetition or quick and regular delivery impossible. Manned Space Remote Sensing experiments cost 1000 times more than unmanned tests for Earth observation.

2.5 Multi Spectral Photography - MSP:

Multilens and multicamera approach only useful to some extent for research in pre-MSS phase for next 5 to 7 years.
Multi-temporal flights essential; digitizing of spectral photos nonsense.

2.6 Specific conclusions:

AP has good prospects in narrow, normal and wide angle large format b & w, colour and colour IR from local, unpressurized aircrafts and from a few special high-altitude jets.
Super-wide-angle era is over the summit; multispectral photography will not become operational.

3. Between Side Looking Airborne Radar (SLAR) and Synthetic Aperture Orbital Radar (SAOR)

3.1 Current operational environment for airborne radar (SLAR and SAAR) mapping

1 Only for small scale mapping (1:400 000 to 1:100 000), hence only infrequently needed, only for extensive areas, and only if maps on these scales are not available.
2 Due to hyper-wide-angle characteristics preferably applied for flat areas (ocean) or almost flat terrain (delta-areas and large plains).
3 Because of all-weather capability SAAR is preferred for cloudy areas over aerial photography; Landsat practice, however, shows that e.g. for the Amazone-delta satellite MSS imagery with 20 coverages per year is already competitive with aircraft radar, in supplying a useful coverage within a year.
4 The data-acquisition capacity being large (10^5 km^2 per day or more), there is only a market for a limited number of SAAR or/and SLAR aircraft. Consequently, flying cost from home base (USA) to work area (ferry flight) is high and makes it unattractive to cover a small area.
5 Taking radar pictures of a country during a few weeks is feasible only for the 30 odd countries larger than 10^6 km^2 (most of which consist of large arid or semi-arid areas), because of the all-weather, around-the-clock capability. Subsequent interpretation takes many years, consequently the data age considerably.
6 Large areas under almost permanent cloud cover are not the economically most important areas to have flown regularly (tropical forest, etc.); moreover, there are not many countries which need and can afford a second integral small scale coverage, if the first one has been taken a few years before.
7 Among the countries which are large, flat, cloudy, rich, etc., the only developed countries using SLAR and SAAR are those with arctic territories (USA-Alaska, Canada, USSR-Siberia), the only OPEC countries which might use radar for surveying are Nigeria (partly), Venezuely, and Indonesia.
8 Special SLAR and SAAR missions for quick local surveying of cloudy, inaccessible areas for oil and mineral exploration, timber exploitation management, etc., as practiced in Latin-America and Indonesia are based on the timely delivery of the synoptic pictures, independent of weather and season. These isolated radar-aircraft activities may continue for some years, until satellite radar will be regularly available; in the mean time, satellite MSS will compete with airborne radar in many cases when the cloudcover is not continuously 100 %.

3.2 Technical environment for airborne radar surveying and monitoring

1 SLAR and SAAR require high investments; operational expenditures are high per aircraft (5 M$/y). Low price per area 10 $/sq.mile ≈ 10 DM per km^2, relatively high price if small scale is taken into account. Equipment could be operated throughout the year, but due to lack of orders, the effective usage in hours/year is reduced considerably.

2 Because of limited application, the equipment for acquisition and processing is produced on special order; consequently prices are high and will remain high.
3 SLAR (real aperture) with long antenna along fuselage of aircraft can deliver developed pictures in the aircraft during flight within minutes after passing over an area. Spatial resolution is limited to some 30 m alongtrack and across-track (Pixel size 30m x 30m). Short wavelengths (8 mm or 3 cm) prevent use in heavy rainstorms.
4 SAAR (synthetic aperutre airborne radar) pictures have yet to be reconstructed from a signal film by means of optical (holographic) techniques, possible in specialized optical laboratories. Spatial resolution better than 30 m possible with stable aircraft, flying on a straight course. Wavelength range extends into decimeter radiowaves, thus provides all-weather capability.
5 Off-line optical processing of SAAR data will in future possibly be replaced by digital or hybrid electronic computer processing if CCD memories with huge capacity become available; primarily for military applications (real-time) and only for civil applications if economy is assured.
6 Technological possibilities for poly-frequency and dual polarisation have still to wait for military de-classification; their usage may become important for vegetation studies over cloudy areas in the mid-eighties (resonance effect occurs when wavelength equals leafdimension; structure of vegetation is revealed in the HH and HV polarized images), see SAOR.
7 Radar shows isolated details well if they reflect electromagnetic energy in the radiowaves well (conductive, metal constructions; concrete; roofs; wet vegetation; and in general man-made details, especially military constructions and vehicles).
8 Geometry of flat areas is depicted reasonably well in ground-range SLAR images; height information is more difficult to obtain; stereo-viewing is possible but not always easy; objects having constant height standing on a horizontal plane do not have equal parallaxes.

3.3 Developments in Orbital Radar

1 Synthetic Aperture Orbital Radar (SAOR) is a side looking radar with an antenna rather large (50 λ) alongtrack, but smaller in the 45^{o} from the vertical direction, to direct a 1^{o} bundle alongtrack, respectively a 5^{o} bundle across-track to the earth surface. 8 mm < λ < 20 cm ?
2 NASA will launch in 1978 a SAOR satellite "Seasat", which will be able to take 30 m resolution pictures over selected land areas (and coarser over sea). Look direction 45^{o} $\pm$ 1.5^{o}, swathwidth 80 km.
3 Advantages of satellite radar are manyfold:
: Spatial resolution can be as good as from aircrafts, or even better; along track integration of signals during 10 km track is possible due to fixed orbit; acrosstrack resolution depends on the measurement of echotime differences, which can be carried out equally accurate from both vehicles.
: The almost constant look angle (43.5^{o} to 46.5^{o}) offers possibilities for automatic processing of textural information.
: The relatively steep look angle allows the surveyance of hilly terrain, which increases the possibilities for application considerably.
: It will be possible to take only a single frame of 80 km x 80 km within a certain country, which enlarges the number of potential user countries enormously.
: Interpretation can keep pace with acquisition, ensuring that interpretor always works on recent data.
4 The economic application of satellite radar is strongly supported by the oceanographic application (seastate: e.g. wave spectra, amplitudes and directions, to be used for routing of surface vessels and determination of evaporation, together with weather satellite data); even if over land SAOR would only be used over clouded areas, the cost-benefit ratio may be advantageous.
5 Radar satellites are a kind of remote sensing vehicles on its own; the orbit has to be selected such that the satellite always receives the sun's radiation on its solar cells, because of the high power consumption of this active remote sensing technique. In this way the satellite may pass over an area twice a day, namely once early in the morning around sunrise, and again in the evening at sunset.
6 With a 24 h service and a 80 km wide swathwidth (single sided SAOR), three radar satellites in tandem in the same sunsynchronous semi-polar orbit can provide a weekly coverage at the equator (6 days temporal resolution), a 3 days coverage at 60^{o} latitude, and even better at higher latitudes.

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7 Police surveyance by means of a satellite radar system has a weak point, as the moment of acquisition can be predicted. Therefore it should be backed-up by aircraft real aperture SLAR or by airborne real-time SAAR, as the pictures are required immediately for direct action.
8 Similar argument give justification for military operated side looking radar. The need for continuous observation of disaster areas, especially when flooded, or for traffic monitoring at sea gives reasonable arguments for some national or regional airborne radar capability.
9 If SLAR is available, it can be used for monitoring purposes occasionally; it should be realized that processing of aircraft radar data will probably be more cumbersome and therefore it may not become operational if satellite radar or even satellite MSS is available.

3.4 Specific conclusions

1 SAOR has possibilities for economic viable operation in the mid-eighties for monitoring (vegetation and water) of areas which are often under cloud cover during the year (tropical forest belt) or during a season (monsoon, winter, etc.), if combined with ocean surveying.
2 SLAR and real-time SAAR have in the eighties some place for local monitoring and civilguard operations; the immediate availability of pictures for direct decisions does not provide time for geometric corrections and automatic processing: visual inspection will do.
3 SAOR offers pictures with reasonable spatial resolution (10 m (?) to 100 m) and good geometry of semi-flat and flat areas. For perfect planimetry and height, use AP, LTP, or satellite MSS once a while. Don't correct radar picture geometry.
4 The number of countries in which SLAR and SAAR pictures are available and used for mapping and resources inventory is now about 12; it will not substantially increase in the near future, due to the availability of Landsat pictures and awaiting experimental Seasat pictures in 1978.
5 Sea-surveyance and arctic regions monitoring will fix the specifications for orbital radar; the LDC's requirements will probably not all be fulfilled.
6 Countries applying SAOR regularly in the eighties for monitoring over their territory may amount up to some 50, if acceptable receiving stations can be operated in those LDC's where the weather is an argument for radar.
7 For topographic mapping, the small scale radar imagery has serious drawbacks compared with aerial photography or intermediate scale satellite MSS. The impact in this classical domain will soon be zero, after the Radam project is finished. There is a possibility that SAOR has something to offer for the quantitative "biomass" vegetation surveying in semi-arid zones, due to the oblique (45^o) viewing direction, as there vegetation in usually very sparse, especially if viewed vertically downward.

4. Thermography in the Infra Red and Microwave wavelengthbands

4.1 Definitions and abbreviations

1 Thermographic Remote Sensing during daytime is possible in the far infrared atmospheric window (FIR: 8-13 µm) and in the microwave domain (8 mm - 10 cm and more). During the night, the middle infrared waveband (MIR: 3-5 µm) offers an additional possibility; it can under favourable circumstances also partly be used during daytime.
2 Possible names for this technique are: Infrared Thermography IRT; Passive Microwave Radiometry PMR; Infrared line scanning IRLS, and FIRT and MIRT for the far and middle infrared thermography, if one wants to be specific.
3 A classification which pays attention to the number of bands is for instance:
Single band thermography, working either in a substantial part of the MIR, or in the FIR, or in the microwave range.
Dual band thermography, working with 2 bands in the FIR; or 1 in the FIR, 1 in the MIR; or a pair in the microwaves.
Hybrid thermography, with one band in the MIR or FIR, the other(s) in the visible range VIS or in the near infrared NIR (Landsat C: 1 FIR, 2 VIS, 2 MIR).
and: Multi Spectral thermography MST, with several bands in the FIR (for example 6) and some in the MIR (2 or 3): NASA aircraft scanner.

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4.2 Physical environment for Aerospace Thermography

1 Unfavourable circumstances for IR thermographic surveying are:
dense vegetation cover (leaftemperature is corrected and stabilized by evaporation);
humid soil and wet objects (it levels extremes and smoothes temperature);
wind speeds at surface over 4 m/sec. (object temperature becomes airtemp.);
high absolute humidity in atmosphere (absorbs some MIR and FIR energy);
high air temperature (self emission);
clouds, fog, rain, etc. (IR remote sensing is certainly not "all weather");
snow and ice cover (for IR an obstacle, not for PMR).

2 PMR thermographic surveying is hardly affected by atmospheric circumstances, but humid objects and wind are obstacles. PMR reacts on surface roughness, therefore on viewing angle for average outdoors objects (except watersurfaces). PMR has yet a very low spatial resolution, even if airborne. Synthetic aperture techniques are theoretically possible with a satellite array, but economical not feasible. Multispectral PMR can give information on sea ice thickness, on the basis of selective absorbtion by the ice of the heat waves emitted by the water. PMR has some depth penetration in objects (a few mm to cm) due to the long wavelength, it thus measures internal temperatures.

3 PMR is essential for surface temperature determination of oceans; the required spatial resolution is of the order of 1000 m (pixelsize 1 km^2), the relative temperature resolution should be around 1°C, the absolute accuracy 1°C or better (for evaporation calculations). A difficulty is in the large variation of the spectral emittance for different materials, e.g. water/land, and the dependence of the emittance on material composition, e.g. salt contents of seawater.

4 Due to the dynamic character of the thermal conditions - changing under the influence of sun, clouds, slope of terrain, wind, dust on surface, rain and dew, nightly emission period, etc. - it is advisable to fly more than once over the same area.

5 A proper selection of frequency and timing is to cover the same area twice a day, namely at about 15h (hottest time of the day), and at half an hour before sunrise (coolest soil temperature). This is useful when the weather is stabile and favourable for thermography, see above (1).

6 Flying an area twice and taking pictures at the same scale and with the same perspective (same flightline) is already very difficult at daytime, let alone at nigth. Therefore, if one wishes to use the thermal inertia of the subsurface materials (the first 20 cm to 1 m) for structural or thermal anomaly detection (heat capacity, temperature conductivity, moisture, trapped air, etc.), satellite thermography is almost necessary from the naviation point of view.

7 Because of the fact that vegetated areas are less appropriate for thermographic surveying, and because of the fact that the slope of the terrain relative to the sun affects the temperature, operational thermography for mapping purposes may well be restricted to the arid zones and to the semi-arid zones. In these areas, a spatial resolution of 100 m will usually suffice for a thermal reconnaissance, consequently satellite thermography may do the job.

8 An essential advantage of orbital thermography versus aircraft thermography is the frequent overpass possible with satellites, as differential thermographic surveying (day minus night data) requires rather stringent weather conditions, if one wants to have an optimum series of pictures. Even in desert areas, wind may blow the surface sand layer to a different place in the 12 hours intermediate period. The interpretor should have several sets of pictures and learn to select the optimal pair.

9 Additional advantages of satellites are the steep view through the atmosphere (reducing the need for atmospheric corrections), the small relief displacement (allowing comparison of image pairs taken from a slightly different orbit) and the small variation in the look-angle at the terrain (if surface not smooth).

4.3 Methodological problems with thermography

1 Thermography of homogeneous surfaces, notably of water (sea, river, lake) and snow is directly possible, because the emissivity (a material property like reflectance, therefore it should preferably be named emittance) is constant over the whole area and very close to unity for IRT (and about 0.3 for PMR).

2 With water, a typical physical problem still exists. Coolingwater output of industry and power-stations is usually warmer than the surface water in which it is released. If above 4°C, the warm water lies on top of the cooler layers, and by airborne thermography, the distribution of the cooling water in place and time can be recorded. This is not the case below 4°C, nor is it possible to detect a cool stream in a warm lake by these "superficial" remote sensing

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methods, as the cool water dives under the warmer, and thus lighter, surface water.

3 With inhomogeneous surface materials (water, rock, wood, clay, sand, etc.) another more fundamental problem arises. As the emitted spectral radiant energy depends on object temperature and on the emittance (differing from material to material), with one measurement it is not possible to decide which factor or which combination of the two factors is responsible for the measured energy anomalies, as there are two unknown factors.

4 With multispectral thermography, n spectral radiant energy measurements are carried out, but there are n + 1 unknowns, namely n spectral emittance values and one temperature. Although the relative impact of the one additional unknown factor becomes less when increasing n, it is theoretically not possible to find an exact solution. In practice it is possible to make one reasonable assumption and solve the set of equations for T and for a number of spectral emittance values, by applying Planck's law.

5 The spectral emittance values are characteristic for the surface materials, their roughness and structure, slope, degree of surface, wetness, moisture, etc. This spectral characteristics is a static material property (except the aspect dry-wet), which can be used to identify the material, especially if it contains silicate SiO_2.

6 The temperature is a dynamic material condition, influenced as it is by many weatherfactors, but it can be used to get some depth penetration, as it contains some information of the upper 1/4 to 1 m of the terrain.

7 The material condition temperature also contains a historical component, as temperature differences fade away relatively slowly, for instance in hours. (This is why the military use it, namely to see past activities, for instance the temperature shadow of an aircraft on a parking area on which it stood one hour ago).

8 An additional methodological problem is the collection of groundtruth data and of atmospheric data for corrective processing. By nature of the dynamical character, it is impractical to collect proper temperature data by fieldwork at a later moment, in another season, in another year, because sunelevation, vegetation cover if existing, weather during the previous hours, etc. are not likely to be the same, and are at least unknown during the flight. The thermal properties and the thermal inertia of surface water (non-streaming) offer the best "passpoints" namely water surface "reference-temperatures" for a wide surrounding area.

9 Aircraft underflights at the moment the satellite passes over is nonsense, as it only covers the same very small area (under the same angle) at the same moment; a cloud for the sun a moment later when the aircraft comes along is already spoiling the correlation looked after.

10 Fieldwork at the moment of airborne or spaceborne thermographic data acquisition is equally unfair; a team can only have instruments at a few points, for which open water should preferably be selected. If earth scientists don't become more dynamic than the objects they study, then they will never discover the secrets. A pre-processing methodology would help to find the proper approach.

4.4 Possible developments of thermographic remote sensing

1 The static and dynamic properties of thermographic information, together with its considerably indirect depth penetration in bare soil and possibilities for seeing in the near-past and identifying certain materials make experimental multi-spectral thermography attractive for the late seventies, early eighties. Emphasis will probably be on arid and semi-arid zones, if mapping of land areas is intended.

2 Proper pre-processing of multi-spectral thermographic data may also yield a first order correction for atmospheric influences; until this and other methods have been worked out will thermography remain where it is now: Useful for forestfire prevention, nice for an occasional flight over a polluted river or lake, but not economically attractive for survey companies for operational work.

3 Meteo satellite thermographic multispectral instruments operate already now in 14 spectral bands for the determination of vertical temperature profiles in the atmosphere, hence the technology is available in a crude from (poor saptial resolution).

4 Some experiments will continue in the dozen or two western countries and in Japan, USSR and maybe some LDC's. Thermographic records of some areas (Malta, Ethiopia) are available for study through UNDP funded projects executed by FAO, other international organisations and survey companies.

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5 Landsat C, to be launched in 1977 (?) will have one thermal sensor in the FIR with a rather poor spectral resolution. If pictures become available, it will, during some time, stimulate thermography experiments. It is, however, not at all clear how one can use reflective VIS and NIR data together with FIR data; it is quite well possible that it will be a fiasco.

6 NASA has plans for an experimental heat-mission satellite with IR thermography in an afternoon - early morning orbit. This orbit differs significantly from the Landsat daytime sun-synchronous orbits, and it cannot be combined with the optimal radar satellite orbit either. Launching before 1980.

7 ESA plans an experimental passive microwave radiometry satellite in the early eighties. This satellite could become an essential tool for ocean surface temperature sensing; if so, the NASA experimental heat-mission satellite will not easily develop into an operational system, when only useful for semi-arid areas.

8 There is a small place for some airborne thermographic surveyance systems for the police, for research, forestfire prevention and so on. Mapping will not be an important usage, monitoring may be a reasonable application. In this case, geometrical corrections are not essential for an operational system, and exact temperature indications are less important than a fair relative accuracy. Visual interpretation suffices.

5. Via airborne MSS to Orbital multispectral sensing: OMSS

5.1 The philosophy behind Multi Spectral Sensing of the earth

1 MSS is only justified for surveying if objects can be identified only (or almost only) on measured "colour" data. If height, location, shape, texture, size, and so on suffice to identify object, use AP or radar.

2 Colour is a property of an area, not of a border between two fields, hence MSS is typically an area survey technique, especially useful for the identification and qualification of homogeneously coloured areas.

3 The economically important areas with a specific colour (for identification) and uniform colour are usually not smaller than 10 m x 10 m (or, if one wants to emphasize "economical", 30 m x 30 m); if smaller, shape, heights, location, etc. are often required, so AP is needed.

4 The primary applications of MSS have to be found in the study of vegetation and of bare, coloured soil, provided the colour gives useful information.

5.2 Definitions relevant to multispectral remote sensing

1 Multispectral remote sensing can be carried out in various parts of the electromagnetic spectrum, as UV, VIS, NIR, MIR, FIR, Microwaves. Usually, airborne or satellite MSS is confined to a part of the NIR (0.5 μm - 1.1 μm Landsat 1;2) but it can include some MIR and FIR bands (Landsat C, NASA aircraft scanner).

2 The number of bands in MSS may be anything between 4 and 24, but it is clear that the extremes are not characteristic for a future operational system. That will more likely have 6 to 10 spectral bands, either in VIS + NIR, or in MIR + FIR. The first will probably keep the name MSS, the latter should be called Multi Spectral Thermography MST.

3 In this paragraph we restrict ourselves to the reflective part of the electromagnetic energy (solar radiant energy reflected by the earth), thus up to 2.5 μm. At the short wavelength side, 0.5 μm forms the practical cut-off for surveying of land and vegetation; for underwater penetration 0.40 μm or 0.44 μm is a better choise although the blue-green light is scattered considerably in the atmosphere.

4 The number of bands is indicated by the expression Spectral Resolution; in addition one should know the exact location of the various bands and their width.

5 The number of levels in which the radiant energy is sampled is indicated by the Intensity Resolution. Usually, the number is a power of 2; the exponent being the bit-number. For instance 32 levels requires 5 bit information capacity. The bit-rate is the number of bits times the number of pixels measured per second; for instance 8 Mbit/sec.

6 Spatial Resolution refers to the pixel size, i.e. the area on the ground from which the radiant energy is integrally measured during the very short time that the instanteneous field of view is directed to that area. The IFOW is a fixed property of a scanner; a typical value for an aircraft MSS scanner is 3 mrad (0.2^o) across. From an altitude of 1000 m, the pixelsize along the projected flight track is 3 m x 3 m = 9 m^2. The IFOW for aircraft MSS is yet

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restricted by military classification, not by technical limitations. Satellite MSS can be made 100 times better (30 m x 30 m from a 1000 km orbit) without military restrictions.

7 Temporal Resolution indicates the number of days (0.1 to 1000) between successive flights over the same area, if carried out continuously (satellite). The effective temporal resolution will usually be less due to cloud cover; it is possible to define an effective mean temporal resolution on the basis of having 90 % of the area recorded by a series of k images through a partial cloudcover which moves irregularly over the area.

5.3 Inherent shortcomings of airborne MSS

1 The wide-angle characteristics (sideways: acrosstrack only) of airborne MSS (up to 60° from the vertical) have some serious consequences.

2 The reflectance of vegetation is more or less constant if measured up to 20°, but changes when going to 25° and 30°, and often obtains a completely different character for larger angles, because of orientation of leaves, occurence of shadow, looking partly under the trees, etc. In addition atmospheric influences vary strongly with look angle.

3 An angular resolution of 3 mrad calls for a flying altitude of 1000 m if the pixel area has to be smaller than 10 m^2 along the projected flight track. However, due to the influence of the $(\cos\alpha)^{-3}$ factor, the pixel area under 45° becomes 25 m^2, under 60° it is already 72 m^2 for flat terrain. For hilly terrain, a 5° sloping plane may increase the pixel area at 60° to 120 m^2, a 10° plane gives 225 m^2, a 15° plane 520 m^2 if the slope is oriented unfavourably away from the flightline.

4 In non-flat areas, the flying altitude should be reduced substantially if one wants to use a reasonable swathwidth. An angular value from -45° to +45°, for instance, with maximum terrain slopes of 15° requires a H=500 m if the pixel area has to be smaller than 40 m^2 all across the strip.
This restricts the application in hilly terrain considerably, because the rule that the maximum height differences should be less than 10 % of the flying altitude has to be adhered at.

5 Unlike stereoscopic interpretation of aerial photography, possible through the forward overlap within a strip, MSS stereoscopy can only be obtained in the side overlap. Problems arise due to scale changes in x and y between strips of successive flights. Lack of a rigid geometrical base prevents accurate slope and height determination, necessary for correction. Moreover, the average intensity value of a field seen in two adjacent strips under completely different aspect angles is not a good basis for automatic processing of MSS data.

6 Current cost of geometrical and radiative pre-processing of 1 hour airborne MSS data costs at this moment about 5 to 8 times the actual flying costs (France). After this investment, the actual production of imagery, the interpretation and/or the automatic processing has still to be executed.

7 Reducing the swathwidth by reducing angular coverage with a factor 3 probably reduces the pre-processing cost for the same area by a factor two, and as the flying cost increases threefold, the total cost of acquisition and pre-processing may come close to a minimum for the area concerned, while the two costfactors are in better balance (approx. 400 $/h for each).

8 However, by flying with a reduced swathwidth by reducing angular coverage, the capacity per flyinghour is reduced too, and as the weather is usually limiting the number of useful days and hours, the economy of aircraft MSS is tempered.

9 Reducing the angular coverage gives an opportunity to increase flying altitude with the same angular resolution and the same spatial resolution along the edges of the strip. This widens the application in rough terrain, and also increases the coverage per hour.
Shrinking the angular coverage still mire, one ultimately arrives at satellite MSS, with the additional advantage of strongly reduced pre-processing costs, if required at all.

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5.4 Advantages of satellite MSS

1 Due to the high altitude (for instance at 600 km; or at 950 km), hardly any geometrical correction is required prior to visual interpretation. If angular coverage is kept small (from +10° to -10°), radiometric corrections, to compensate for changes in lookangle, are usually not needed.

2 Due to the sunsynchronous orbit, the local suntime at pass-over is constant throughout the year. Consequently, sun elevation and azimuth change little from week to week; shadow direction and length are almost constant during the time crops mature, and practically equal at 180 daypairs through the year.

3 A satellite in a circular orbit provides MSS pictures which have a constant scale. Proper attitude control assists in getting temporal pictures which match when superimposed. Proper orbital control reduces differential relief displacement in pictures taken several months apart to an acceptable level.

4 The huge acquisition capacity of well-designed satellite instrumentation allows the recording of waste areas if the weather happens to be reasonable once during the time the satellite passes over. An aircraft would need several hours to cover a local area with the same spatial resolution; often the weather situation does not allow acquisition over an extended period.

5 Comparing the capacity of airborne MSS and of orbital MSS on a worldwide scale is reasonably well possible if one assumes that a regular coverage is required of the 10^7 km^2 und cultivation (10 % of total land area). One Landsat MSS can picture this area (if cloud-free) in 18 days with a spatial resolution (pixelsize) of 0.5 ha. An MSS aircraft at H = 10 km and angular coverage of 2 x 45° has a similar pixelsize along the edges of the strip. Per flyingday of 5 hours and with a speed of 500 km/h, it will record 20x500x5 = 5.10^4 km^2. In 18 days about 10^6 km^2 are recorded, hence 10 aircrafts are needed to cover the 10^7 km^2 green world once in 18 days, and 100 are required for the 10^8 km^2 total land area.

6 An advanced high altitude aircraft with expensive MSS equipment costs 5 M$ a year; the 10 needed for a worldwide 18 days vegetation survey amount up to 50 M$ a year, assuming cloudfree operation and no loss of time for maintenance. As an 18 days temporal resolution is insufficient for real work, the 50 M$ is a lower limit, also because of the fact that the spatial resolution of future satellites can be much higher.

7 Cost of an operational satellite system like the (experimental) Landsat is estimated at about 50 M$ per year. Landsat-1 was expensive: 200 M$; Landsat-2 costs about 50 M$; a series of 40 satellites with standard parts is estimated by USA industry to cost 8 M$ per satellite in orbit in the eigthies. Useful life: 3 years per satellite.

8 An important advantage of satellite MSS versus aircraft MSS is the fact that it brings this remote sensing technique in all countries of the world, whether small or large, poor or rich, cloud free or often partially clouded. Education and research results can be made available for all and, moreover, be suitable for all, if organized well.

9 Last, but not least, comes the most typical advantage of satellite MSS: the high temporal resolution possible. An 18 days cycle is possible with one satellite and a rather restricted angular coverage; a 2 days cycle requires 7 satellites in a lower orbit with a somewhat wider angular coverage. There are indications that a weekly coverage requires a 2 days cycle, because of cloudcover.

5.5 Current status of airborne MSS and orbital MSS

1 Airborne MSS is available for research in some 6 countries in Europe; to this number one should add USA (many pieces and types), Canada, USSR, Brasil (?), Iran, India (?), Thailand, Indonesia, Philipines (?). It is difficult to estimate the extent to which MSS is in operational use; it seems as if, in spite of the concentration of research on airborne MSS data processing, the technique is not operational yet in USA.

2 With Landsat-2 in orbit and the availability of thousands of tapes and pictures from Landsat 1 and 2, MSS research changed direction from aircraft to spacecraft data acquisition and processing. Europe may still be in the airborne experimental phase, the USA has almost abandoned the aircraft MSS and aims on satellite MSS for improved yield estimation of american food and fibre crop as soon as possible (before 1980).

3 Gradually the idea of repetitive coverage by satellite MSS finds supporters, although it hardly is presented in its ultimate strength in papers and reports. Too many research workers respond to the question "How often do you need an MSS picture of your fieldarea?" with: "Once in 18 days!" as if they don't understand the question, biased as they are by the existing technology.

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4 Nevertheless NASA reported as a result of an inquiry that onethird of the potential users want to have satellite imagery within a week after the acquisition by the satellite scanner; if later, they don't need them anymore. Conclusion of NASA: the delivery of Landsat-pictures has to be speeded up from several weeks to a few days. Conclusions of an outsider: the period between request and acquisition should be shortened to a few days; and the 9-days temporal resolution of the Landsat 1 and 2 together is still much too long, especially if cloud cover is taken into account.

5 Extrapolating the gradually growing awareness for a better temporal resolution in satellite MSS (for Nevada desert a 2-days cycle was requested after the rainy period), it is clear that aircraft MSS is losing the battle.

6 Orbital MSS, however, is still in the experimental stage. The US Congress has not yet agreed to give way for an operational system. Political problems seem to be the barrier; a better spatial resolution is necessary (and quite well possible) for an economic impact, but international concern about the distribution of the much more detailed pictures is growing. After Landsat 2, Landsat C will very likely be launched, but it is uncertain to what extent the current equipment at the user can be used for the operational systems of the eighties.

7 The conclusion must be that the future is to the satellite MSS systems, but this future is yet too uncertain to invest in hardware and software for operational applications, let alone to educate large groups of users already now.

8 Still one has to realize that many countries are willing to be active in space, several have proposed earth observation satellites (FRG, Sweden, Canada, the Netherlands, France, Japan studies on a proposal, etc.), and the international organisations, notably the UN Committee on the Peaceful Use of Outer Space (COPUOS) and its sub-committees, encourage the set-up of systems which would make available survey data to all member countries.

6. The development of Orbital MSS into Orbital Multi Temporal Sensing (OMTS)

6.1 On the temporal aspect of Satellite MSS

1 The primary application of satellite survey data will (on the long run) be to survey dynamic features, hence mapping (map making) is not so essential as is the acquisition of recent data to support management.

2 The planimetry of the pictures has to be sufficient for direct comparison with a map, height information should not be taken from satellite imagery, as aerial photography and Lear-Tek photography supplies it better.

3 For surveying of dynamic objects (vegetation, water, urban area change detection) a dynamic survey activity is needed. Remote Sensing for Dynamic Surveying bridges the gap between the highly dynamical meteoservices (1 day turnover time) and the forestry service and topographic service (3 years turnover time).

4 Satellites can give repetitive coverages up to 1 day temporal resolution or better; satellites are not justified for surveying features which change little in a few years. However, satellite imagery can of course be used in the static earth sciences, once it becomes available. A new methodology will develop to incorporate recent satellite imagery of the seasons with an old aerial photographic coverage for, say, geological interpretation.

5 If a weekly picture is needed, than there is hardly time to apply geometrical corrections and spectral corrections, no time for fieldwork, enlarging of pictures (especially not for colour enlargements) and so on, because the user should have pictures within days and finish interpretations before the next picture has been taken. After this moment, motivation for 'old'pictures drops.

6 For dynamic surveying, a regular flow of some spectral pictures with a frequency which matches the dynamics of the objects studied is more important than the occasional burst of a full multispectral set of pictures.

7 Minimizing the amount of information to be processed at one moment, but optimizing the regular flow of information is for several reasons (economy, routine, continuity in the work of a few specialists, etc.) a good approach. When thinking this over, it is clear that for dynamic surveying, temporal resolution has a higher weight than spectral resolution, at least if one considers it per discipline.

8 One more reason can be found for minimizing spectral data output to a small number. Visual processing of 3 spectral images in a colourcomposite is possible and forms the best base on which, after one has enough experience, automatic processing may be developed. The worldwide introduction of satellite MSS pictures is easiest with false colour photographs for dedicated interpretors, of which many are motivated to work on their own pictures of the

local region they are responsible for.

9 The availability of a regular series of pictures of the local area will have a great impact on environmental studies in institutes, universities and services. Here again it is better to supply many people with a few colour-composites of the area, and in the period they wish, than to supply few persons with many tapes and spectral pictures they didn't ask for.

10 The specific application of multi-temporal and (multi)spectral satellite images are in agriculture, rangeland management, ecological studies, natural vegetation studies, forestry; in all fields of activity in which water plays a role (irrigation management, hydrology, snow cover estimations, run-off predictions, evaporation, salinization, flooding, drought, powerdam management); in rural and urban surveying (change detection, monitoring).

6.2 Orbital Multi Temporal Sensing and its consequences

1 If the temporal resolution is so important, than it is better to express this by stating that the future is to Multi Temporal Sensing (MTS) instead of Multi Spectral Sensing.

2 Naturally, the satellite can have an 8 to 10 band MSS instrument on board, but the available images are tri-colour copies. A principal component transform can be applied to filter the information in a disciplinary-specific manner and to concentrate the bulk of the useful data into three synthetic spectral bands, from which a false colour picture can be made.

3 Research with multispectral photography and with aircraft multi-spectral scanners has to be seen in the frame of the scenario sketched here (or a modified scenario if you have objections against the one presented). Consequently, to develop geometrical corrections for multispectral scanner imagery is not a rewarding task for an operational institute, although it can serve as a subject for a Ph.D. thesis in an academic environment.

4 To develop an operational procedure for airborne MSS data processing is, within this concept, even a bigger R&D management failure. When one has solved all the theoretical problems, aircraft MSS has been followed up by satellite MSS, and when the practical problems are solved, satellite multi-temporal sensing is reality.

5 Multispectral colour viewers have no place either in operational dynamic surveying with multi-temporal images. It takes too long to arrange the pirctures and the colours; as soon as a workable procedure is found, its implementation will be introduced as a routine in the pre-processing phase (electronic computer) and a proper hardcopy image is available for lab and fieldwork.

6 The availability of one satellite remote sensing system will have a negative impact on other satellite and aircraft remote sensing systems, except aerial photographs, as the revival of AP in the USA shows already.

7. The place of the other Remote Sensing Techniques

7.1 Within the context of the title and summary of this paper, a detailed discussion on other RS techniques than Radar, Thermography and MSS (and Aerial Photography) was not intended. However, a realistic appraisal of Remote Sensing can not be given without sketching a scenario for the less glamourous techniques, because some are already in operational use for long. Here we will only mention some of them.

7.2 Airborne Magnetometry
Scintilometry (Radioactivity)
Electrical Pulse techniques
Snifflers for molecules in air and atoms (Hg)
Correlation Spectrometry
Lidar
Acoustical underwater techniques
etc.

7.3 Most of these techniques have to be airborne, either because satellites are too far away to obtain useful survey data, or because the information carrier does not penetrate in space.
In combination with aerial photography, some of these techniques will be very useful and develop together a kind of integrated remote sensing.

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8. General Conclusion and Statements

8.1 Those who are concerned about (or in charge of) R&D management start to see certain trends and lines along which the development may go in the next decade.

8.2 Policy makers and managers have still to bridge the gap between the current status of RS and the probable operational activities in the eighties.

8.3 Satellites are the appropriate vehicles for the big three remote sensing techniques; this opens possibilities for dynamic surveying. Satellites still add to the national glamour, funding of satellites is more likely than of aircrafts.

8.4 Aerial photography will be the basis for height information, planimetry, size and shape; its applications will probably grow, except the SWA photography, provided the Lear-Tek project develop well.

8.5 The USA stated in 1974 (Rome-Fracati ESRO Symposium) that within 5 years crop yield prediction of american food and fibre crop is the aim of satellite MSS. The non-USA scientists and politicians should remember what President Kennedy said about putting-a-man-on-the-moon in the beginning of the sixties and how it worked out before the decade ended.

8.6 The heavy concentration of research and testing on satellite MSS has two effects: An "International-Geophysical-Year" effect, due to the fact that once the critical mass is passed, the development goes rapidly; and the concentration on one technique prevents scientists and countries to get enough money and manpower in several other techniques to have an impact on the state-of-the-art.

8.7 It is important that the current leaders in the Survey departments try to cope with the developments and soon play an active role in the incorporation of satellite remote sensing in their services, even if new departments have to be set up. (Environmental scientists and technicians; vegetation; water). Atomic energy commissions or aircraft industry and laboratories do not have sufficient background in surveying to get RS operational for mapping and monitoring.

8.8 Automatic data processing by central computers of pictorial information is still in the far future; the recent development in the USA tends to visual interpretation of somewhat preprocessed colour photographs. Visual processing of satellite data is possible when developing a good strategy; later the fixed routines can be automated gradually.

8.9 Instead of wanting to derive all information needed for management from remote sensing records, we better think of another approach.
Develop a thorough understanding of environmental dynamics and try to discover the key-factors, which can be seen when looking from orbit weekly at a fixed time.

8.10 With a regular serie of real time images of our own region, we are in good position to learn from nature to think in terms of a model for the dynamic phenomena at hand. For checking a predicted development, only little information may suffice, and automatic processing of a whole picture becomes a waste in time! and money.

8.11 In operational dynamic surveying (between meteo and topographic surveying) there is hardly place for a combination of satellites, aircrafts (for real-time underflight), ground truth sampling, atmospheric correction, and so on. If necessary in the research phase, it should not be made an integral part of future operational methods.

8.12 It would be interesting to have other scenarios on the table, to discover in serious discussions the most likely outlook on the future. Updating it regularly would require less effort and yield a line in our work.

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A Critical Review of the Status of Remote Sensing

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Abstract

In spite of a decade of massive research and development, the big three remote sensing techniques (Multi Spectral Sensing MSS; Airborne thermography IRLS, IRT, MST, PMR; Side Looking Radar SLAR, SAR) have barely found operational, and certainly not economically viable mapping applications comparable with the main "avant-la-lettre" RS method: Aerial Photography. The analysis presents reasons and offers an outlook on positive developments possible in the next ten years by the proper synthesis of electronic remote sensors and sun-synchronous by orbiting satellites. It will be indicated why there is no place for airborne MSS, hardly a place for Aerial Thermography and scarcely one for SLAR, why there soon will not be an argument for the derivation of precise geometrical information from remote sensing imagery, and why the principal application will not be mapping but MONITORING of dynamic features for better management.

Eine kritische Rückschau auf die Stellung von Fernerkundung

Zusammenfassung

Trotz eines Jahrzehnts intensiver Forschungs- und Entwicklungsarbeit haben die drei großen Remote Sensing-Techniken (Multispektral Sensing MSS; Flugzeug-Thermographie IRLS, IRT, MST, PMR und Sidelooking Radar SLAR, SAR) kaum operationelle und sicher nicht ökonomisch lebensfähige Anwendungen in der Kartenherstellung gefunden, verglichen mit der wichtigsten - lange vor der Einführung des Ausdrucks verwendeten - "Remote Sensing"-Methode, nämlich der Luftphotographie. Die Analyse legt Gründe dafür dar und bietet einen Ausblick auf positive Entwicklungen, die in den nächsten zehn Jahren bei richtiger Kombination von elektronischen "Fernsensoren" mit Satelliten in sonnensynchronen Umlaufbahnen möglich sind. Es wird dargelegt, warum für Flugzeug-MSS kein, für Flugzeug-Thermographie kaum und für SLAR wenig Platz sein wird, warum es bald keinen Grund mehr gibt, genaue geometrische Informationen aus "Remote Sensing"-Aufnahmen abzuleiten, und warum die Hauptanwendung nicht die Kartierung, sondern die Sichtbarmachung dynamischer Vorgänge zur Erleichterung und Verbesserung des Managements sein wird.

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Revue critique de la situation de la télédétection

Résumé

En dépit d'une décennie de recherches et de développements, les applications des trois grandes techniques de la télédétection (télédétection multispectrale MSS, thermographie aéroportée IRLS, IRT, MST, PMR, radar latéral SLAR, SAR) se sont révélées être tout juste efficaces et de toute façon coûteuses pour ce qui concerne leurs applications en cartographie, surtout si on les compare avec la photographie aérienne qui était la méthode de télédétection avant la lettre.

L'analyse faite ici offre une vue d'ensemble sur les développements souhaitables et possibles, pour les dix années à venir, des téléanalyseurs électroniques et des satellites "sun-synchronous". L'auteur précise les raisons pour lesquelles il n'y aura aucune place pour la télédétection multispectrale aéroportée, peu de place pour le thermographie aéroportée et une petite place pour le radar aéroporté latéral (SLAR). Il indique également les raisons pour lesquelles, dans un avenir proche, il sera difficile d'argumenter de l'obtention d'informations géométriques précises à partir de telles images et celles pour lesquelles les applications des techniques de la télédétection ne se situeront pas en cartographique mais dans la gestion des modéles dynamiques utilisés pour un meilleur aménagement.

Revisión critica del estado actual de sensores remotos

Resumen

A pesar de tener una decada de mucha investigación y desarrollo, las tres principales tecnicas de sensores remotos (sensores multiespectrales MSS, termografía aêrea IRLS, IRT, MTS, PMR y radar SLAR, SAR) casi no han encontrado aplicaciones v seguramente ninguna alternativa economicamente realizable en cartografia aplicada que sea comparable al principal metodo "avant-la-lettre" de sensores remotos: la fotografía aérea.

El presente analisis prueba y ofrece perspectivas positivas en el posible desarrollo de las propias sintesis de los sensores remotos electronicos y la sincronización solar de satelites orbitales. Esto estara indicando porque no hay lugar para sensores remotos multiespectrales MSS, dificilmente uno para termografía aêrea y escasamente uno para radar SLAR, pero muy pronto no habra argumentos para la derivación de información geometrica precisa de las imagenes de sensores remotos y porque la principal aplicación no sera la cartografía sino la repetición (monitoring) de caracteristicas dinamicas para su mejor manejo.