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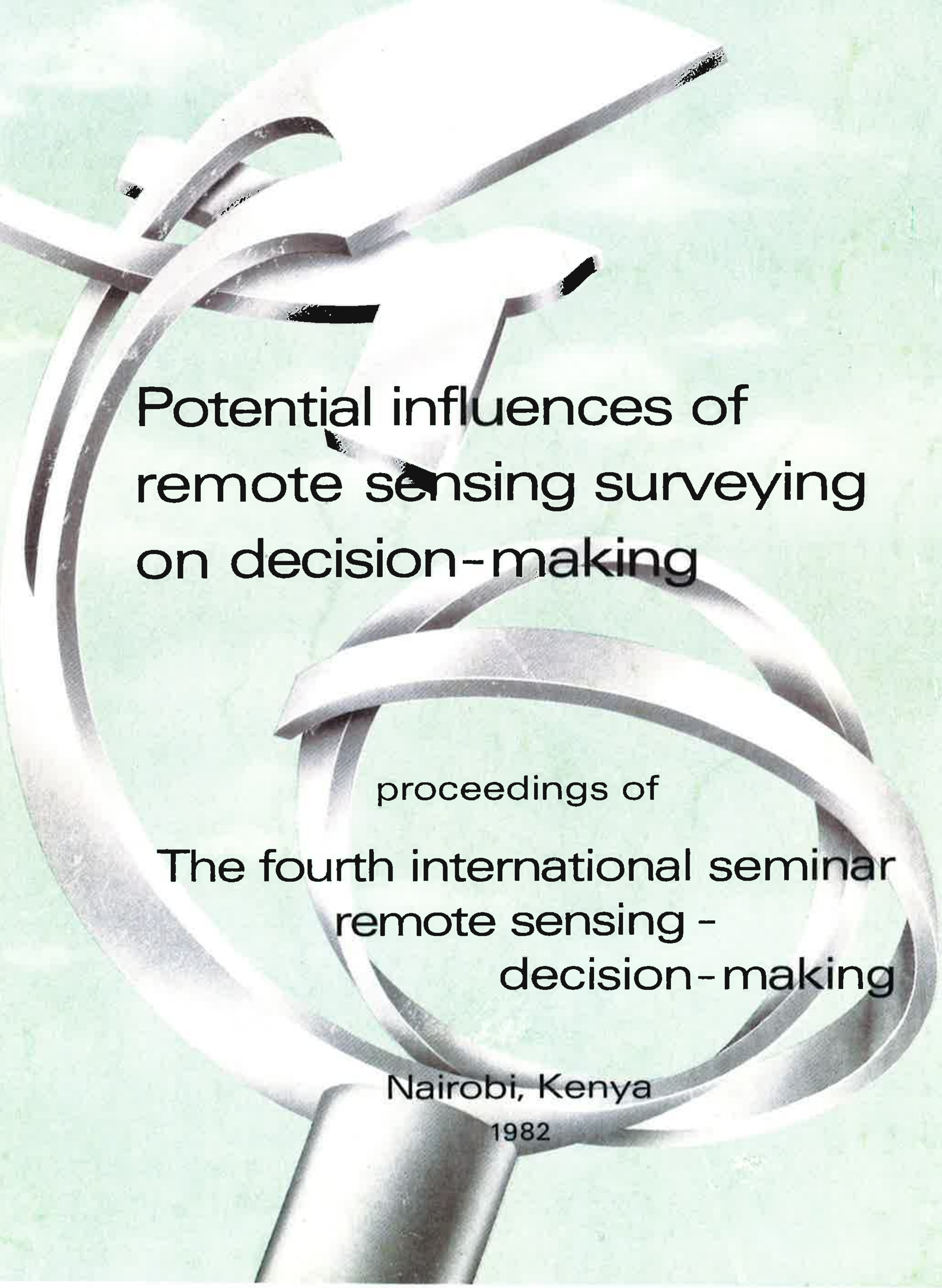

Potential influences of remote sensing surveying on decision-making

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RADAR: AN ACTIVE REMOTE SENSING SYSTEM FOR EAST AFRICA?

F. Leberl

Technical University and Graz Research Centre, Graz, Austria

1. Active Remote Sensing

Out of the group of active remote sensing imaging systems, such as flashlight aerial photography, underwater sound imaging (sonar), laser scanning, pulsed radio wave sensing, only side looking radar seems to have a chance of being applied in the near future in East African countries. Of the non-imaging active remote sensing techniques, pulsed radio wave techniques are applied in airborne geophysical prospecting to determine sub-surface conductivity in selected areas of certain countries. Profiling techniques can also be used in conjunction with small-format cameras in base-line data surveys with low-flying airplanes to determine the distance between camera and terrain at the exposure locations. Non-imaging profiling and altimetry radiowave techniques can support large area, small scale aerial photography to improve the accuracy of photogrammetric operations.
Non-imaging active techniques thus have certain applications in east Africa. Imaging techniques, however, have not been applied so far. Why is it that even side looking radar as the most attractive active imaging system has not been used in east Africa? After all, it has existed since the early 1960s and has been extensively used in central and South America, tropical West Africa, Indonesia, the Philippines, Japan, etc.

A judgement is needed of the capabilities and limitations of imagery so that their applicability in the East African situation can be clarified. To this end, the following is a short review of typical radar images, with a discussion of resolution, reflection, stereo, small scale mapping, aircraft and satellite operations.

2. Side-Looking Radar Imaging

Creating side-looking radar (SLR)
imagery on film is a mature technology. Current further developments are towards digital radar imaging devices resulting in digital imagery composed of pixels. We must expect that fully operational digital radar systems will not be available before the end of this decade. Until then, digital systems will be used only to a limited extent.

Figure 1 reviews the SLR-imaging process employing an antenna of several meters length. This is carried by an aircraft or satellite. Sequential radar pulses illuminate a narrow strip of the earth's surface. Reflections of the pulse are sensed by the antenna and used to create an image line. Thus each pulse results in one line which corresponds to the illuminated terrain strip. The line is recorded, either in digital form on magnetic tape or onto a film.

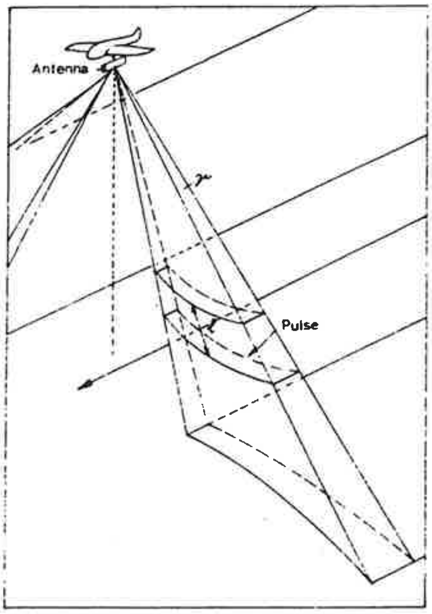


Figure 1 : Side looking radar imaging configuration.

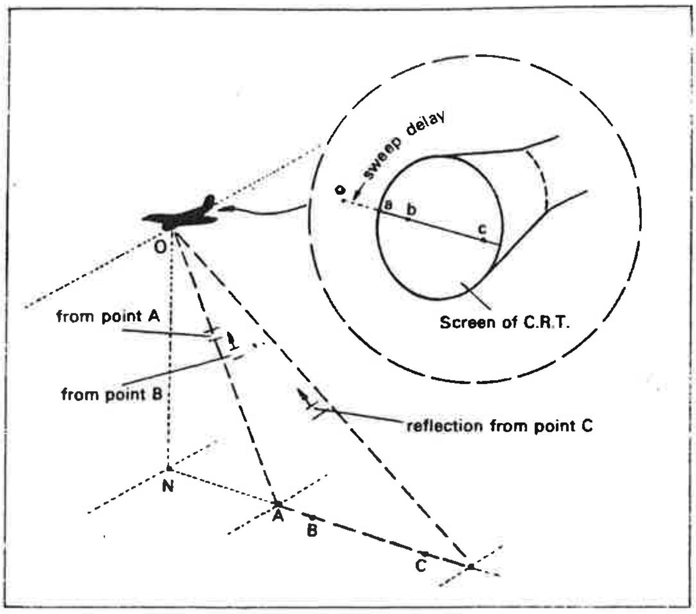


Figure 2: Recording of received radar echoes.
O - antenna position;
N - the projection of O on the ground.
The indicated reflections from the ground are only those parts of reflections that are directed towards the antenna.

A complete image is composed of the sum of all image lines. The terrain is scanned by the forward motion of the aircraft or satellite. The image itself is obtained by writing the digital lines sequentially onto film or by directly pulling film across the recording device (figure 2).

Imaging is thus the repetition of the following steps: pulse transmission, reflection on the ground, receiving of reflections or "echoes", recording. Several thousand pulses can be handled per second since they move at the speed of light.

Figure 3 shows a typical radar image generated from an aircraft. There are distinctive dark and bright tones of agricultural patterns. The essential effect on image brightness here is the roughness of the surface cover: a smooth surface will act mirror-like and does not reflect energy back to the aircraft (fig. 4a); a rough surface will reflect into various directions (fig. 4b). One can thus have various degrees of specular and return reflections.

Figure 3 : Example of an aircraft radar image of an agri-cultural flat terrain.
Flying height 12 km, radar wavelength 3 cm, resolution 3 m.
Courtesy Geodyear-Aero-space.

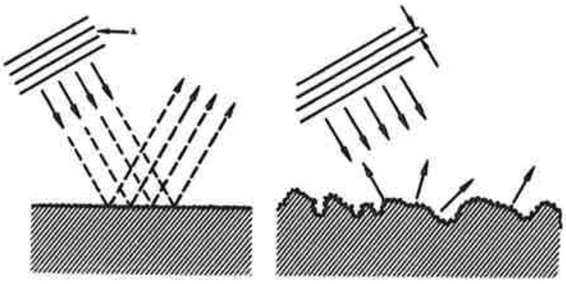
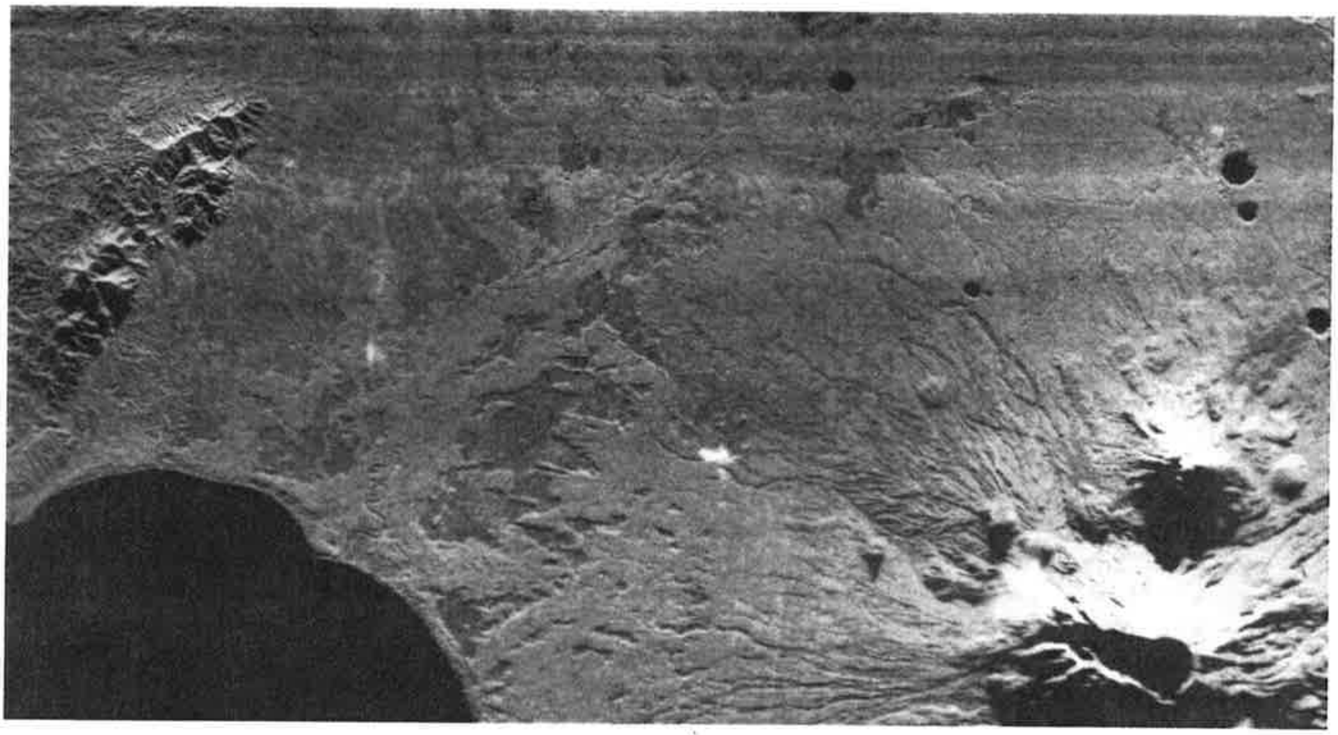


Figure 4 : a) Specular reflection and b) Diffuse reflection

Figure 5 shows a radar image of rougher terrain, taken again from an aircraft. There is a dominating effect of topographic relief on the image brightness. The effects caused by surface roughness variations are too subtle to be noticable in mountainous terrain.

It is clear at this point that SLR images are black and white, monochromatic recordings of terrain reflectivity. Typical wavelengths used are 0.8 cm (K-band), 3 cm (X-band) and 25 cm (L-band). X- and L-band penetrate clouds and rain, where K-band radiation may not do so in all instances.

Figure 5 also illustrates the crisp expression of subtle topographic relief in flat areas. This is an advantageous property of radar images that only occurs in aerial photographs when taken at very low sun angles. Small slopes facing the antenna show up as bright features. Water bodies do not reflect toward the antenna and are black. The image in figure 5 also shows numerous shadow areas. These occur whenever radiation cannot reach the surface since it is blocked by relief.



MARS Aerial Remote Sensing.

Figure 6 shows the geometry of shadowing. Slopes facing the antenna are compressed. In radar terminology, we call this compression effect "foreshortening". In extreme cases one even may encounter "lay-over": an image of a slope is laid over the image of the plane around the mountain.

In images of flat areas, radar reflectivity of the ground is shown as variation of brightness. Given a uniform roughness of the surface, we can measure brightness differences caused by surface moisture.

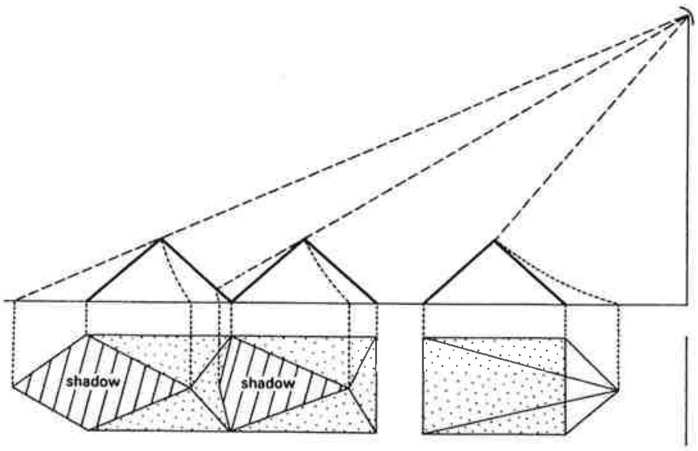


Figure 6 : Geometry of radar shadow, lay-over and fore- shortening. Note that from a given sensor position, all object points are pro- jected into the same image point if they are at the same distance from the antenna. The projection is thus along circles. This is different from the per- spective projection of photography.

3. SLR Geometric Resolution

Detail resolved in a radar image can be judged knowing the so-called "range"- and "azimuth" resolution (figure 7). Across the flight direction, two points are imaged separately if their slant distances (r) to the antenna, differ for more than half the length of the radar pulse. This is around 3 to 20 m. All points underneath an aircraft have the same distance to the antenna. The resolution is therefore poor and imaging underneath the aircraft is avoided.

In the flight direction, two points are imaged separately if their distance is larger than the azimuth dimension of the imaging pulse. This increases for real-aperture radar according to figure 7a. It is constant and independent of range r for a so-called synthetic aperture radar system as presented in fig. 8b. The order of magnitude is also 3 to 20 m. The difference between "real" and "synthetic aperture" radar are essentially those of the electronic system and consequently of geometric resolution. However, the geometrically superior "synthetic-aperture radar" (SAR) has drawbacks in the radiometric resolution: contrast is often better in real aperture images.

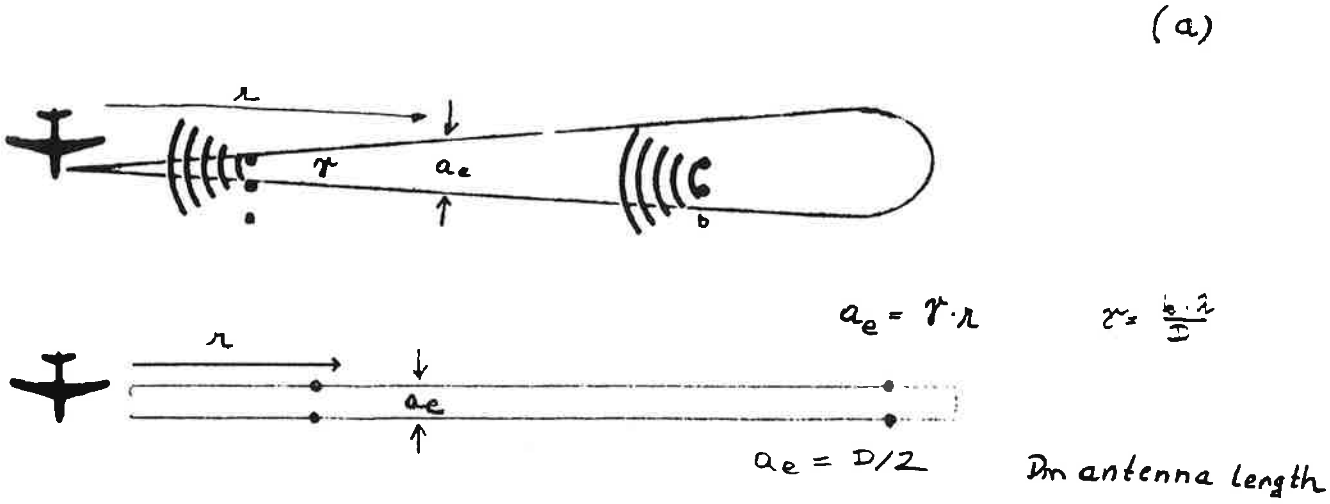


Figure 7 : Definition of radar geo- metric resolution:

a) Real aperture radar.

b) Synthetic aperture radar.

4. Satellite Radar

Radar imaging from satellite is currently being discussed in all major space organisations. The first orbital radar images were from the Moon in 1972, when the Apollo-17 mission carried an imaging radar system to create images of three entire lunar circumferences.

There are terrestrial satellite radar images from flight altitudes of 800 km in SEASAT (1978) and from altitudes of 240 km in the space shuttle (1981). Satellite radar images display a more uniform look angle than from aircraft; therefore there is nearly the same appearance of the surface irrespective of the position within the swath. At these steeper look angles the lay-over effect is gone. Shadows are hardly existing.

We have to expect a number of satellite radar missions in the future. NASA is preparing for another shuttle radar flight in 1984. ESA will have its radar experiment in spacelab shortly before that. ESA (ERS-1), Japan (ERS) and Canada (Radarsat) are seriously developing a spaceborne radar capability.

5. Some Radar Image Properties

Imaging radar sensors use a portion of the electromagnetic spectrum that makes imaging nearly independent of weather: clouds and rain can be penetrated. This penetration capability does not exist for soils and vegetation. Only in very dry soil and with longer wavelength radiation (25 cm) has a sizeable penetration of sand occurred, e.g., in Western Egypt.

Current geometric resolution of radar images is approximately 20 m from satellite, 10 m from aircraft. Resolution is not related to distance from the object. However, it is realistic to assume that no major improvement of resolution will materialize: the higher values today are approximately 3 m. Technologically, a 1 m resolution would be feasible, but the radiometric quality of the image would be poor. Similarly, higher resolution is at the expense of swath widths.

Radar image brightness is dominated by topography: small slopes facing the antenna show up clearly. Therefore man-made features such as roads or railroads can be imaged as white linear elements. However, if slopes do not face the antenna, they will not be imaged distinctly. As a result, the radar image contents depend greatly on flight direction and look angles off-nadir.

On a flat surface, more subtle brightness effects will be present in an image. These are caused by surface roughness and di-electric properties (moisture, type of material). It is of interest to relate radar ground resolution "a" in meters, to an equivalent photographic scale number "M". To do this, we need to make an assumption on film resolution, expressed in n line-pairs per m (lp/mm):

$$M = a \cdot n \cdot 2800$$

This leads to an equivalent photo scale of 1:500 000 for a radar resolution of a = 10 m and film at 20 lp/mm. We see that radar image scales are very small and can be used only for very small scale mapping.

6. Stereoscopic Viewing of Radar Images

For the purpose of enhanced visual interpretation, overlapping radar images can be successfully viewed under a stereoscope. Generally the only flight arrangement producing valid stereopairs is with two parallel flight lines to one side of the imaged terrain surface (figure 8).

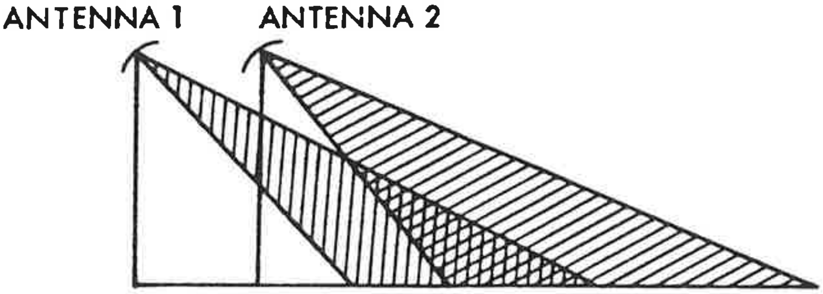


Figure 8 : Same-side stereo radar arrangement.

Benefits derived from stereoscopic viewing are related to topographic expression. Height measurements are not of great accuracy, with errors of terms. A general recommendation for radar is not meaningful.

If a global stereo coverage becomes available from satellite scanning, as for example from SPOT or Mapsat, then topographic relief can be judged from visually observing stereo models or from automatically obtained digital terrain models. This may eliminate some need for radar coverage. However, subtle changes of relief in flat areas may escape because of the limited accuracy of the stereoscopic coverage but may be documented in shallow look angle radar.

Certain monitoring tasks that do not depend on colour information but have a critical time element can be fulfilled by orbital radar. This includes certain vegetation mapping needs. Radar has so far not been explored in detail for its capability in this area. If such capability exists, then an application may also be possible in east Africa in the future.

Clearly radar is a unique tool to measure surface roughness. Whenever this is of relevance, radar can be applied. Processing may not be trivial to unravel terrain slope effects from roughness effects. So far, however, the measurement of roughness has not yet had great practical relevance but was studied scientifically as a natural phenomenon. Penetration into a water body through vegetation and soil is hardly feasible to any useful extent. Only in very dry soil or through modest vegetation such as swamp grass is penetration possible to a higher extent.

In an attempt to judge the applicability of imaging radar in east Africa we quickly see that it is limited. The content of useful, not redundant information in radar images will lead to their use if satellite missions produce inexpensive radar data. Commercial radar surveys are highly unlikely for geo-scientific applications in East Africa. Only the need for sovereignity control at all times (night, clouds), for monitoring capabilities through disasters and for specific exploration data may create an application of radar remote sensing in East Africa.

THE POTENTIAL INFLUENCES
OF REMOTE SENSING
ON DECISION MAKING

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