N7624659

E7.6-10339
CR-147222

I. Title of Report : A Methodology for Small Scale Rural Land Use Mapping in Semi Arid Developing Countries Using Orbital Imagery : II - Capabilities of Remote Sensing Techniques for Land Use Surveys

II. Principal Investigator : Dr. J.L. van Genderen

III. Authors of Report : Lock, B.F. and Genderen, J.L. van

IV. Address of Organization : Department of Geography
The University
Sheffield
S10 2TN
United Kingdom

V. Date Report Written : February, 1976

VI. EREP Investigation No. SR 9686

VII. NASA Technical Monitor : Mr. Martin L. Miller
Code TF6
NASA, Johnson Space Centre
Houston
Texas 77058
USA

(E76-10339) A METHODOLOGY FOR SMALL SCALE RURAL LAND USE MAPPING IN SEMI-ARID DEVELOPING COUNTRIES USING ORBITAL IMAGERY. 2: CAPABILITIES OF REMOTE SENSING TECHNIQUES FOR LAND USE SURVEYS (Sheffield G3/43

N76-24659
HC $3.50

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II. CAPABILITIES OF REMOTE SENSING TECHNIQUES FOR LAND USE SURVEYS USING ORBITAL IMAGERY

2.1. INTRODUCTION

As different features of the landscape exhibit different spectral responses, it is very important that sensing devices employed in land use surveys should be correctly selected and utilised. At the present level of technological development, sensors which record data in the ultra-violet, visible, near visible infra-red, thermal infra-red and microwave portions of the electromagnetic spectrum have the greatest potential (see figures 1 and 2). The most satisfactory sensors developed that have direct applications in orbital land use surveys include photographic sensors, multi-spectral scanners and side-looking radar. The following discussion will consider the nature and limitations of these sensors, especially their suitability for inclusion in orbital earth resources imaging systems. Return beam vidicon systems and independent thermal infra-red systems have not been discussed in detail because interpretation techniques have not reached a satisfactory level that would allow them to be considered as operational bases for orbital land use surveys in the foreseeable future. This is mainly due to the lack of sufficient data from these sensors and research workers have been unable to evaluate their spectral responses and their usefulness for rural land use surveys.

2.2. PHOTOGRAPHIC SENSORS

2.2.1. General

Until recently photographic techniques have been by far the best methods for recording the spatial, spectral and temporal characteristics of land use patterns. According to Thaman (1974) almost all of the operational surveys that have been carried out throughout the world have utilised photographic sensing systems. There is no doubt that they will continue to play a very important role in medium-large scale land use surveys and, due to their excellent spatial resolution and established interpretation methodologies, they will serve also as valuable aids in small scale land use surveys based on orbital imagery.

Photographic sensors are passive and direct in the sense that they incorporate various combinations of cameras, filters and films that are capable of recording the reflected radiation in the visible and near visible portion of the electromagnetic spectrum from approximately 0.3 to 1.1 micrometers (see figures 1 and 2). These sensors do not produce or transmit any energy in order to "illuminate" the earth's surface (c.f. radar) and the varying amounts of reflected radiation are usually presented as positive prints or transparencies (Cooke and Harris, 1970).

There are many factors that still make photographic sensors the most viable method for operational land use surveys at medium-large scales. These include the wide range of film, filter and lens combinations that may be utilised to investigate selected portions of the visible and near infra-red portions of the electromagnetic spectrum. Also, this type of imagery has the advantage that it can be viewed stereoscopically which allows the interpreter to consider the relationship betweel slope and land use either qualitatively or quantitatively. In addition, as it usually reflects closely the actual on-the-ground situation, photographic interpretation is a comparatively straightforward process (Heller, 1970) which can be aided by established methodologies that have been developed over many years (Vink et al., 1965; Olson, 1973; A.S.P., 1960). Interpretation is also assisted by the high spatial resolution of the photography and the relative ease in which the photography may be rectified to give the correct geometric portrayal of the earth's surface. The latter characteristic makes photography an ideal medium for mapping the spatial distribution of land use. Overall, vertical aerial photography and the subsequent film processing and interpretation are operations which do not depend on expensive platforms or sophisticated electronic equipment for image generation and analysis.

However, there are a number of disadvantages associated with conventional photographic sensing. Probably the most important is that it is not an all-weather, day or night system due to the fact it utilises the reflected radiation of the visible and near visible infra-red portion of the electromagnetic spectrum. Therefore, the operational costs in normal airborne photographic surveys are indirectly increased by high aircraft stand-by costs whilst waiting for suitable weather conditions. In satellite photography large areas may be covered by one frame compared with the large number required to cover the same area by conventional aerial photography but much of the photograph may be rendered virtually useless for land use surveys due to excessive cloud cover. Other problems associated with orbital photography involve the return of film from unmanned satellites. Although it is technically possible to retrieve films from unmanned satellites (Clayton, 1974), it is operationally difficult and expensive (Entres, 1974). Also, due to the nature of photographic sensors, adequate protection must be provided to prevent extraneous radiation affecting the film during all stages of the operation.

Consequently, the use of photographic sensors for repetitive, global or regional land use surveys in unmanned long-term satellite operations will be very limited but they will continue to be the major operational technique for obtaining airborne imagery for many years. The latter role will provide important background material required for interpreting orbital imagery obtained by other satellite sensors, especially multi-spectral scanners, even though the photography may be out-of-date and may only partially cover the survey area at a relatively large area, ie. they may provide a type of "ground truth" for orbital data in a similar way that field work provides ground truth for conventional aerial photographic surveys.

2.2.2. Photographic Sensing Systems

It is beyond the scope of this dissertation to provide detailed explanations of the methods used in obtaining photographic images. However, a brief summary of the major components of photographic sensing systems, viz. cameras, films and filters will be presented together with references to relevant articles which contain detailed technical explanations.

There are several types of aerial cameras that have been used for various purposes, eg. vertical framing, trimetrogon, panoramic, continuous strip, divergent forward oblique, forward oblique cameras (see figure 3). Detailed descriptions of each type can be found in Estes, 1974; Jensen, 1968; Navair, 1967; Am. Soc. Photogrammetry, 1968, 1975; Spurr, 1973; Strandberg, 1967. The most common system used in land use surveys has been the vertical framing camera but, in recent years the multi-band (or multilens) adaptation has been investigated as a possible method for obtaining additional photographic information for use in land use surveying (Potter et al., 1974) Lins Milazzo, 1972; Laver, 1971; Yost and Waderoth, 1971 (see figures 2 and 4). The multi-band vertical framing cameras, with their various combinations of lenses, films and filters, have permitted much more detailed investigations of the reflected radiation from features of the landscape within the visible and near-visible infra-red portion of the electro-magnetic spectrum. Some attempts have been made to record the reflected radiation from the ultra-violet region with limited success (Estes, 1974).

Black and white panchromatic aerial photography has been the major operational system used in land use surveys for many years and the comparatively recent introduction of colour photography, both conventional and colour infra-red, has increased the potential information content of photographs. However, the marked increase in costs associated with the production of colour photographs have tended to limit their use, especially in developing countries. Also, in order to interpret and evaluate the imagery produced by these recent air-borne, photographic techniques, a basic understanding of the range and limitations of the overall photographic systems, especially film emulsions, is required. This is particularly necessary in the utilisation of colour infra-red photography where the normal colours of objects are replaced by "false" colours. Furthermore, careful selection of film filter-lens combination is required to provide imagery that maximises the landscape characteristics being investigated and to avoid selecting combinations that produce similar imagery. Detailed explanations of the technical aspects of films and filters may be found in Heller (1970), A.S.P. (1960, 1968, 1975), Levine (1969), Thomson (1973a, 1973b, 1975), Meyer and Maklin (1969), Colwell et al. (1970), Jensen (1968), NAVAIR (1967).

2.3. MULTISPECTRAL SCANNERS

Multispectral scanning systems provide a basis for data acquisition that permits the simultaneous measurement and recording of reflected and/or emitted radiation from various portions of the electro-magnetic spectrum by non-photographic methods. This type of system can provide information that may be used to complement imagery obtained by using photographic sensors as well as recording data outside the spectral range of photographic emulsions. The operational scope of the scanners ranges from the near ultra violet to the thermal infra red ie. from approx. 0.3 µm to 14 µm.

Some of the most sophisticated scanning instruments can divide the relevant portion of the electro-magnetic spectrum into 24 channels and the respective reflectance or emittance levels can be recorded on magnetic tape. Operationally only 4 bands have been implemented in Landsat 1 and 2 scanning systems and 13 bands were used in Skylab (see figure 3 and tables 1 and 2). Roberts (1975) states that 'it does not automatically follow that an increase in accuracy is obtained by increasing the number of channels. He refers to research that has demonstrated that only a relatively small increase in accuracy of classification is obtained when using 12 bands as compared with 4 or 5 bands. He also points out that it has not been possible to make any general rules with regard to the number and spectral range of bands that should be used.

There is no doubt that multi-spectral scanners will play a major role in future small scale land use mapping based on orbital imagery and that it will be the dominant system employed in this type of survey for the next decade (Clayton, 1974; Savigear, 1975; Hempenius, 1975). The primary advantage of multispectral scanners over other remote sensing systems is that recorded information can easily be relayed to earth receiving stations from the unmanned satellites. Also, this system can acquire data about portions of the electromagnetic spectrum that are not easily obtained by other sensors. The data collected are suitable for digital conversion and can be made readily available in computer compatible form for automatic processing in a wide range of investigations.

Overall, multi-spectral scanners provide data acquisition systems that embrace a comparatively broad spectral range and, when combined with satellites, they have the capabilities to permit almost continuous monitoring of the earth's surface. The synoptic overview and the limited amount of geometric distortion give the orbital multi-spectral scanning systems the most potential for small scale land use mapping in the forseeable future.

Unfortunately, certain limitations still exist with orbital multi-spectral scanning systems. The most important include the relatively poor spatial resolution, eg. approximately 78 metres and Landsat 1 and 2 imagery and 50 metres on Skylab imagery and, in many investigations, expensive equipment and trained operators have been required to analyse and interpret the data. In addition, as multi-spectral scanners record reflected and emitted radiation, they do not have the all-weather, day or night flexibility of radar. Consequently, in any particular orbit large areas of the earth's surface may be rendered unsuitable for the acquisition of data due to cloud cover. However, the relatively rapid orbiting of the earth often allows sufficient coverage of the earth to be obtained and, with the recent launching of Landsat 2 and the future launching of Landsat 3, the temporal resolution will be improved considerably providing that the sensors continue to function. Another disadvantage is that stereoscopic viewing is not normally possible by using forward overlap within a strip. Until recently it could only be obtained through side overlap (van Genderen, 1974; Poulton, 1973) but, an innovation by the U.S. Geological Survey Astrogeology Division has been introduced whereby the digitised 1:250,000 topographic map data covering a scene is merged with the Landsat image data and the appropriate displacement is completed to produce any desired parallax (Beaumont, 1975). Unfortunately, this technique will not be feasible in many developed and developing countries due to the lack of adequate, quantitative topographic map information.

Although the spectral characteristics of many land use features can be measured and recorded on magnetic tape and later reconstituted into visual imagery by many different techniques, the problem of data interpretation has lagged far behind the capabilities of multi-spectral data collection.

As different materials possess different reflectance, absorption and emission properties, much research has been investigated in order to determine the specific spectral signatures of the various features of the landscape, eg. vegetation, rocks, minerals, water, soils. The identification of unique spectral signatures would enable the data obtained from remote sensors to be automatically classified. But, according to Savigear (1975), most of the research has been carried out under strictly controlled laboratory conditions and the signatures determined in this manner can only provide a guide for the selection of spectral bands that should be used in operational surveys. With regard to the search for unique spectral signatures in crop surveys and the idea that a library of "crop signatures" could be produced, Roberts (1975) reports that this approach has been abandoned by most researchers. He states that it is now apparent that "at the present stage of development, spectral data can only be interpreted meaningfully when it is compared with ground truth or training sites which are close in space and time to the survey area".

Factors that have affected the amount of recorded radiated, or emitted energy from a particular crop include the time of day as well as the time of the year in which the measurements were made. These temporary aspects affect the level of solar illumination and the stage of crop growth and have presented major problems for researchers attempting to develop automatic crop classifying procedures. The major developments have occurred in parts of the U.S. where large scale monoculture is practiced but LACIE (Large Area Crop Inventory Experiment) appears to be the only technique that has reached an operational level (Allen, 1975). Therefore, despite earlier over-exaggerated claims, it appears that the use of the data obtained from orbital multi-spectral scanners for the automatic production of detailed land use maps will not eventuate in the near future especially in developing countries. This will be particularly relevant in areas where the landscape is subjected to a wide range of crops and where the field sizes are small and fragmented. The probable trend during the foreseeable future will involve the utilization of certain computer based techniques to assist in visual interpretation.

More specific explanations and a wider range of references dealing with the various aspects of the utilization of MSS data in land use surveys are provided in the general review in Chapter 3.

2.4. RADAR

Radar is the only viable remote sensing system, other than photographic sensors and multi-spectral scanners that appears to have any real potential for obtaining land use data from orbiting platforms in the foreseeable future (Hempenius, 1975). As an active remote sensing system, radar provides its own source of illumination in the microwave portion of the electromynetic spectrum. The nature of this illumination can be controlled to a high degree but, because it is usually based on a single frequency between 0.8 cm and 1 metre rather than a spectral band used by passive sensors, the use of radar in vegetation and land use studies are limited unless both like and cross-polarised imagery are taken simultaneously (van Genderen, 1975).

Due to its active nature and the utilisation of longer wave lengths, radar has all-weather, day and night capabilities which produces a distinct advantage over photographic sensors and multi-spectral scanners. Long term flight planning can be carried out and aircraft standby costs markedly reduced. Also, it enables monitoring of agricultural crops at critical phases, even if adverse weather conditions exist at the time. Additionally, it can provide the basis for an accurate system for the recognition of land surface features (Entres, 1974).

With regard to the future use of orbital radar, Hempenius (1975) listed many advantages of Synthetic Aperture Orbiting Radar (SAOR). For example, it is expected that the spatial resolution of Seasat SAOR (to be launched in 1978) will be 30 metres which will be at least as good as present operational airborne radar and the broad swath wide will provide a good synoptic overview. The almost constant look angle may allow the automatic processing of textural information to be carried out and the relative steepness of the look angle will considerably increase the range of applications by permitting detailed investigations of hilly terrains. However, Hempenius believes that the major land use application of SAOR when it becomes operational in the mid-80s will be to monitor vegetation in areas which are subjected to occasional or seasonal heavy cloud cover as well as investigating sparse vegetation patterns in semi-arid zones. But these tasks will be supplementary to the major role of SAOR in monitoring sea and ice characteristics.

As with other remote sensing systems the characteristics of the recorded imagery are caused by the interaction of the properties of the sensor system and surface phenomena and serious misinterpretations could occur if the interpreter does not understand the basic principles underlying the image formation. This problem is particularly evident with radar and Domville (1974) stressed that, if the full operational potential of radar imagery is to be realised, it will be necessary to embark on a considerable research programme devoted primarily to the recording, processing and interpretation of the data obtained. Additional support for the need for more research into the interpretation of radar imagery comes from Morain (1974) who has investigated the use of radar in vegetation mapping. He believes that researchers have only just begun to explore the content of radar imagery and the best ways to interpret it, especially with regard to the meaning of tone and texture. Furthermore, he suggests that it would be highly desirable to develop a true multi-spectral capability for use in vegetation science.

The problems associated with interpreting radar imagery are greater than with photographic images although many similar factors including the image characteristics of tone, texture, size, shape and stereo can be utilised. This is due to the fact that the radar system provides its own source of illumination and the nature of the reflectance of this energy by the target makes the accurate identification of ground features more difficult. The amount of energy returned to the radar sensor is dependent upon the properties of the transmitted electromagnetic energy and, subsequently, the imagery itself include the operational wave-length, polarization, look direction, flying height, size and type of antenna. The properties of the surface phenomena which can affect the imagery include the dielectric and conducting properties, the surface roughness and shape, surface slopes, vegetation cover and the nature of the sub-surface materials. Detailed discussions on these aspects may be found in EASAMS, Vols. 1-6, 1972, de Loor, 1969; Domville, 1974; Holter, 1970; Nunnally, 1974 and reports on applications of radar in vegetation and land use surveys can be seen in Morain and Simonett, 1966, 1967; Simonett, 1968, 1970; Viksne et al., 1969; Morain, 1974.

2.5. RETURN BEAM VIDICON

The television camera usually favoured for orbital remote sensing is based on the return beam vidicon (Entres, 1974) which contains a photosensitive surface on which an image is exposed initially and an internal scanning device converts the picture of relative radiation intensities to an analogue signal. This signal can be telemetred directly back to an earth recording station or tape recorded and sent later (Langrebe, 1972) in a similar manner multi-spectral scanners. Vidicons are restricted to approximately the same spectral range as photographic sensors and, due to the relative ease of data retrieval they could prove to be a viable alternative to photography in unmanned satellites as well as supplementing the data collected by multi-spectral scanners.

The return beam Vidicon used on Landsat 1 recorded imagery in 3 bands viz. 0.475-0.575 μ (green, 0.58 - 0.68 (red) and 0.83 (near 1R) (Stone, 1974). Unfortunately, the system malfunctioned and had to be shut down a month after launching and insufficient data were obtained to allow a realistic appraisal of the imagery and its potential for providing information for small-scale land use surveys.

2.6. SUMMARY

Nunnally (1974) states that although a series of independent studies have been carried out by researchers interested in specific remote sensing systems there has been no attempt to evaluate in a systematic manner "the relative effectiveness of all the different persons capable of recording land use data". Even though this statement is quite correct, it tends to be more relevant to air-borne techniques rather than orbital because only one remote sensing system is operational for obtaining orbital land use data.

As mentioned in the earlier discussions about various remote sensing systems that have potential applications in orbiting satellites, the only viable technique that will permit the rapid and regular collection of data for small land use surveys during the next decade will be multi-spectral scanning systems. Even though photographic sensors can offer much better spatial resolution and relative ease of interpretation the problem of retrieval of exposed film severely restricts their ability to provide continuous monitoring facilities. In addition, multi-spectral scanners can provide data in a form that is more suitable for digital conversion and automatic processing. Radar has not yet reached a satisfactory level of development to be considered as an alternative orbital remote sensing system and according to Hempenius, Synthetic Aperture Orbital Radar (SAOR) will not provide adequate imagery for land use monitoring for a decade. But its all weather, day or night capabilities would make radar a very important addition to the multi-spectral scanner if problems of interpretation, rectification and data storage can be overcome. Thermal infra-red line scanners appear to have limitations and cannot be considered as important alternative land use data techniques and will only be able to provide supplementary information. Return beam vidicons have distinct advantages but have provided insufficient data to allow satisfactory assessment of their potential in providing satellite imagery for small scale land use surveys.

However, multi-spectral scanners will not provide a panacea for small scale land use surveys but at the present stage of technological development, they offer the major advantage that information gathered by this method can be readily retrieved and stored in computer compatible form. Also, the data have the capacity to be reconstituted into a series of images singly or in varying combinations of spectral bands at scales up to 1:250,000 or larger allowing regular synoptic overviews of the earth's surface. But unfortunately, the collection of data by orbital multi-spectral scanners has outstripped the development of interpretation techniques. Many researchers have investigated a wide range of automatic and semi-automatic techniques using authentic and simulated Landsat and Skylab data. However, there are very few organisations in the word that are capable of utilizing the information that is being obtained from the current operational satellites. Furthermore, no proven techniques have been developed that will allow automatic identification of features of the earth's surface without associated ground sampling. Owen-Jones (1975) believes that it will be highly improbable that completely automatic interpretation will be achieved. Human decisions and assistance will be required but the level and nature of the human assistance varies amongst researchers and much work is still being carried out in many different disciplines.

Savigear (1975) suggests that the research involving the evaluation of the use of multi-spectral scanning data should be considered in two separate but related programmes. The research involving the identification of unique spectral signatures should be an important long term situation. But, for the short term, he believes that the uses of multi-spectral data in different types of environments in regions of limited area should be identified and assessed. Also, the research programmes should be oriented towards the requirements of the region rather than the world scene. Eventually the identification of the different spectral, spatial and temporal properties of different parts of the region may lead to the development of a satisfactory semi-automatic system for regional analysis until multi-spectral data. However, this would involve more refinements of current interpretation techniques and ground truth procedures as well as the establishment of detailed and tested methodologies for carrying out particular investigations. In the case of small scale land use surveys, particular attention would be required in the formation of a suitable land use classification scheme and the effects of seasonality on image identification. Overall, the short term approach would be particularly helpful for many countries who could benefit from the relatively inexpensive and readily accessible multi-spectral scanning data if a satisfactory methodology for conducting small scale land use surveys primarily based on orbital MSS data could be established.

Hence, this section has shown that most of the machine assisted methods used in the developed countries are experimental rather than operational and that there is a lack of detailed methodologies suitable for use in developing countries. Consequently, there is an immediate need for a simple approach in order to maximise the usefulness of readily available MSS data by workers in developing countries to obtain relevant and reliable land use information.

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TABLE 1

TYPES OF SENSORS CARRIED ON LANDSAT SATELLITE

(formerly ERTS - Earth Resources Technology Satellite)

SENSOR: RBV - multispectral camera system

Spectral bands: 0.475 - 0.575 μ
0.580 - 0.680 μ
0.690 - 0.830 μ

SENSOR: MSS - multispectral scanner system

Spectral bands: 0.5 - 0.6 μ
0.6 - 0.7 μ
0.7 - 0.8 μ
0.8 - 1.1 μ

TABLE 2

TYPES OF EREP (Earth Resources Experiment Package)

SENSORS CARRIED ON SKYLAB SATELLITE

SENSOR: S190 - Multispectral Photographic Facility

Spectral bands:	0.5 - 0.6 μ	(Pan X)
	0.6 - 0.7 μ	(Pan X)
	0.7 - 0.8 μ	(B&W I.R.)
	0.8 - 0.9 μ	(B&W I.R.)
	0.5 - 0.88 μ	(Colour I.R.)
	0.4 - 0.7 μ	(HiRes Colour)

SENSOR: S191 - Infrared Spectrometer

Spectral bands:	0.4 - 2.4 μ
	6.2 - 15.5 μ

SENSOR: S192 - 13 Band Multispectral Scanner

Spectral bands:	0.41 - 0.46 μ
	0.44 - 0.51 μ
	0.52 - 0.56 μ
	0.56 - 0.61 μ
	0.62 - 0.67 μ
	0.68 - 0.76 μ
	0.78 - 0.88 μ
	0.98 - 1.08 μ
	1.09 - 1.19 μ
	1.20 - 1.30 μ
	1.55 - 1.75 μ
	2.10 - 2.35 μ
	10.2 - 12.5 μ

SENSOR: S193 - Microwave System

Spectral bands: 13.9 GH_2

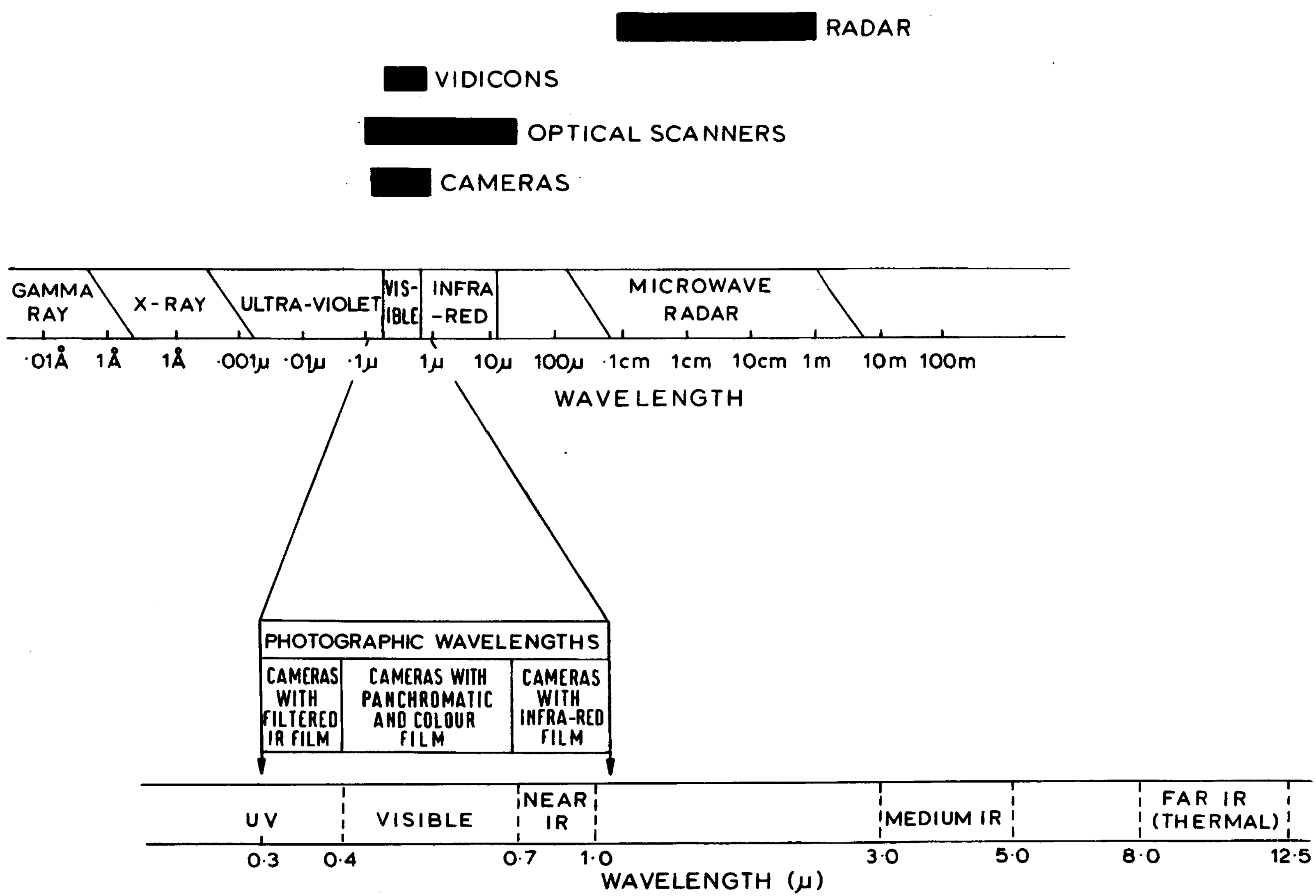

Figure Spectral relationships of various remote sensors used in land use surveys

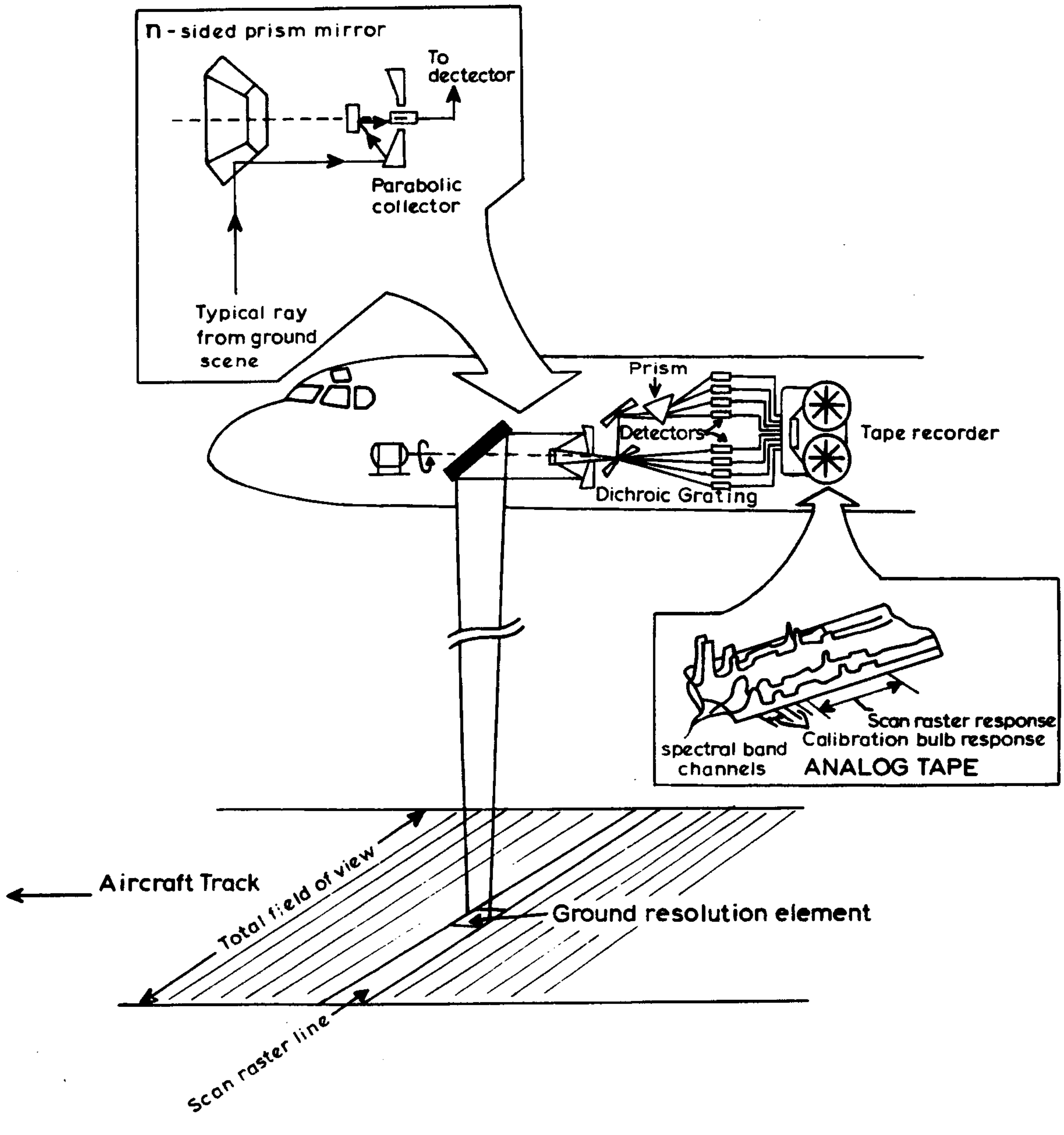

Figure Simplified diagram of an airborne multispectral scanning system (adapted from Estes, 1974 and Langrebe, 1971)

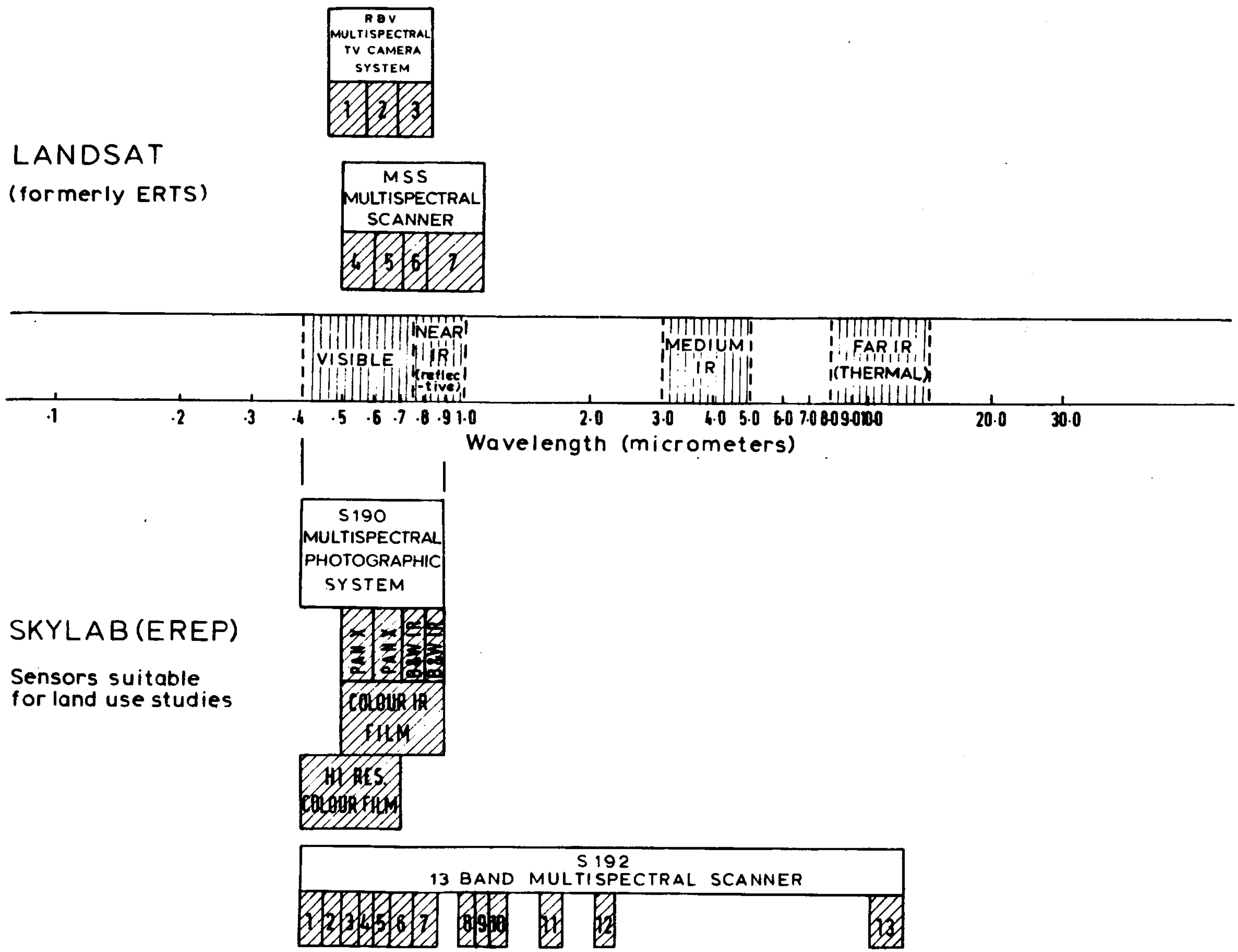

Figure Simplified diagram showing spectral bands of Landsat and Skylab (EREP) Sensors