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Remote Sensing for Environmental Sciences

Edited by Erwin Schanda

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Preface

The public's serious concern about the uncertainties and dangers of the consequences of human activities on environmental quality demands policies to control the situation and to prevent its deterioration. But far-reaching decisions on the environmental policy are impaired or even made impossible as long as the relevant ecological relations are not sufficiently understood and large-scale quantitative information on the most important parameters is not available in sufficient quality and quantity.

The techniques of remote sensing offer new ways of procuring data on natural phenomena with three main advantages

— the large distance between sensor and object prevents interference with the environmental conditions to be measured,
— the potentiality for large-scale and even global surveys yields a new dimension for the investigations of the environmental parameters,
— the extremely wide, spectral range covered by the whole diversity of sensors discloses many properties of the environmental media not detectable within a single wave band (as e.g. the visible).

These significant additions to the conventional methods of environmental studies and the particular qualification of several remote sensing methods for quantitative determination of the natural parameters makes this new investigation technique an important tool both to the scientists studying the ecological relationship and the administration in charge of the environmental planning and protection.

The aim of the present volume is to disseminate some knowledge on recent methods of remote sensing and their applicability. This book is an introduction for natural scientists and graduate students wishing to become acquainted with these methods and to take over this new tool in their specific investigations. Particular emphasis is put on the new methods which, though still in a stage of development offer considerable potentialities as operational systems in the near future. Information on the technology applied and still more on the basic investigations and large-scale applications are of recent date and represent therefore a valuable review even to the specialists. We have not striven for completeness, which is impossible within the available space, but have preferred to produce a readable textbook rather than a many-volumed handbook. Some established sensing methods (mainly those in the optical and near-infrared range) are therefore presented in a considerably reduced form, in favor of more recent developments. The selection of topics for this book and of material treated within the various chapters has been made with the aim of illustrating the variety of methods which are representative and important for future applications in the widely spread natural disciplines; the examples of application in the natural sciences are given essentially to demonstrate their feasibility, while their ecological discussion has been strongly limited.

Of the total of nine chapters seven are on specific sensor methods and one is on image processing, which is important to all types of sensors and all spectral ranges as soon as some imagery is involved. Each of the sensor chapters contains

— a description of the basic techniques and the sensor systems employed,
— a treatment of the physical fundamentals of the object-sensor relation (i.e. a translation of earth-science parameters into sensor-specific observables),
— a discussion of a number of illustrative applications of the particular method.

The emphasis and length of each of these topics is very much dependent on the type and stage of development of a sensor. The authors of the various chapters are highly experienced specialists in their respective technical fields (physicists and electronics engineers) and are deeply involved in earth-science applications. This background makes them particularly qualified to present their methods to readers interested in earth- and life-science as well as to those more technically oriented.

I should like to thank my author colleagues for collecting all pertinent material for their respective chapters, for their consideration of the common purpose and for delivering their manuscripts within a very short period. I acknowledge also the valuable advice of the publishing company and the series editor Prof. O. L. Lange. My special thanks are due to my wife Gabriele and my children Susanne, Christine and Rüdiger for their patience with the burden of my additional work during this time.

Bern, October 1975 ERWIN SCHANDA

Contents

1. Introductory Remarks on Remote Sensing

E. SCHANDA

1.1 Application Areas of Remote Sensing

The increased potentialities of the remote sensing techniques—in particular the new methods outside the visible part of the electromagnetic spectrum—and the growing experience in a variety of civil applications during the last decade demonstrated new ways to the solutions of many problems of the natural sciences and opened a broader view on the relations between various large scale natural phenomena. But the potential utilization of the remote sensing technology to many public services and managements, which is not yet fully realized, may be expected to bring even more important achievements during the next decades by the qualitative and quantitative improvement of the remotely sensed information and due to the increased effectiveness of their procurement. This can be achieved by the possibilities of quick, small to medium scale (e.g. ground-based or air-borne) but detailed, multi-sensor observation of special features within small areas or by less detailed, large to global scale (space borne) but repetitive and synoptic surveying.

The following list is only a modest and somewhat arbitrary sample of application areas and topics for which immediate gain may be expected:

Water

— Water resources inventory and management for agricultural and industrial use.
— Storage of water in the snow and ice cover and run-off forecast.
— Distribution of the humidity of the soil.
— Water quality (chemical, thermal and biological waste discharge control).
— Sea-ice boundaries and sea state (shipping).
— Thermal streams and salinity distribution in the oceans (marine resources, fish farming).
— Coastal zone, estuary and harbour activities.

Land and Vegetation

— Land use (inventory and planning).
— Soil classification and conservation (agricultural production, irrigation).
— Mineral inventory and exploration planning.

— Control of plant diseases (crop and forest protection).
— Disaster assessment and prediction (volcanos, earthquakes, landslides, avalanches).
— Land pollution control (waste disposal, contamination).
— Cartography.

Atmosphere

— Global weather mapping (cloud distribution, short-range warning).
— Horizontal and vertical temperature and water vapor distribution (all-range numerical weather forecast).
— Control of contents and distribution of minor constituents of the upper atmosphere on global basis.
— Pollution control of the lower atmosphere within limited areas (industrial and automobile emission).
— Survey of the earth's radiation belt (interaction with non-terrestrial phenomena).

Others

— Wild life control and protection.
— Survey of radiation hazards from nuclear power plants.
— Updating of the growth of urban areas.
— Traffic surveying and control.

There may be very different priorities for the utilization of remotely sensed environmental data in different regions of the world e.g. in extremely densely populated parts of Europe as compared to nearly unexplored polar or equatorial regions. But obviously there exists an urgent need for the availability of remote sensing tools as an aid for developing nations in fields such as

— basic land use surveys and inventories of resources.
— location of areas for mineral and energy prospection.
— establishing and updating of maps.

1.2 Sensing Systems

Remote sensing systems have to offer various levels of sophistication of the sensing capabilities, of the various degrees of reliability and of the various stages of the information processing, dependent on the areas of application and on the degree of development from experimental to operational utilization:

— Unambiguous identification of a feature to be observed (relation between the observables and the natural parameters of the object).
— Continuous or intermittent monitoring of temporal changes of the observed features.
— Mapping of the spatial distribution of the observed natural parameters and thematic data and image processing.

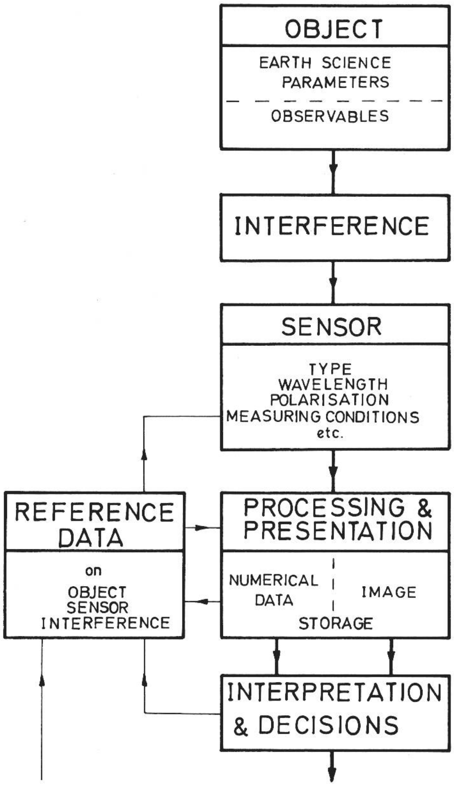

Fig. 1. Block diagram of a remote sensing system with optional automatic interpretation and decision. A complete system will comprise of several complementary types of sensors. The reference data will be generated by previous knowledge and by automatic adjustment

— Thematic interpretation of the observed features (relevant to the specific fields of the users) and automatic prediction.
— Judgement of the information, decision finding, eventually execution of action.

The last two—the highest—levels of performance are to some extent interfering with optional or compulsory intervention of man.

A block diagram of a complete sensing system including the object to be sensed, the interference by the medium carrying the information from the object to the sensor, and finally the—either human or automatic—interpretation and action, is presented in Fig. 1. In most cases there is no identity between the natural parameters and the observables (e.g. the distribution of an atmospheric constituent versus intensity and shape of a spectral line). The sensor itself, however, is nothing more than a transformer of the received information about the observables into an image or into an electric output voltage to be used in the data processing. Images are therefore in most cases only presentations artifically made in a format familiar to the user. Thus the output of a sensing system provides a new type of information in a "language" which is different from the language of the conventional description of the environmental parameters, and the untrained user will need time to learn the meaning of the new information and to readjust his concepts. This not only because of the unconventional kind of presentation, but even more because of the above-mentioned difference between the observables and the natural features themselves. Therefore the main problem of utilizing modern remote sensing methods is not so much the sensor technology or the techniques of data processing and presentation, but the translation of the observables to be sensed into the environmental parameters to be actually controlled. The prime aim of many applied research programs today is the attempt to understand what the sensor output data mean and how they can be used. The existence of reference data on the environmental phenomena (e.g. "ground truth" experience and instantaneous adjustment) and its correct use in the information processing is of eminent importance for the reliability of the interpretation. In a singlewavelength sensing situation there is almost always a smaller number of observables than there are parameters characterizing a natural phenomenon, and therefore an unambiguous identification is strictly impossible. A typical situation of this kind is the interpretation of black and white photography by the exclusive use of the albedo of the objects (no shape recognition). Table 1 gives a selection of the ranges of the albedo of various natural surfaces (as given in various handbooks and textbooks). There is a wide range of overlapping albedos around 30% in the visible spectrum. From this it becomes evident that a remote sensing

Table 1. Albedo of various surfaces (integral over the visible spectrum)

Surface	Percent of reflected light intensity
General albedo of the earth	
total spectrum	~35
visible spectrum	~39
Clouds (stratus) < 200 meters thick	5–65
200–1000 meters thick	30–85
Snow, fresh fallen	75–90
Snow, old	45–70
Sand, "white"	35–40 (increasing towards red)
Soil, light (deserts)	25–30 (increasing towards red)
Soil, dark (arable)	5–15 (increasing towards red)
Grass fields	5–30 (peaked at green)
Crops, green	5–15 (peaked at green)
Forest	5–10 (peaked at green)
Limestone	~36
Granite	~31
Volcano lava (Aetna)	~16
Water: sun's elevation (degrees)	
90	2
60	2,2
30	6
20	13,4
10	35,8
5	~60
< 3	>90

system—even for a rather limited range of tasks—has to consist of sensors of various types and in various spectral ranges.

1.3 Remote Sensing and Spectral Constraints

The methods to be used for the remote probing of environmental parameters have to be selected due to their ability of transmitting the information of the observable over sufficiently long ranges to the sensor without unrestorable loss. The best suited principles are those based on the transmission of electromagnetic waves, which exhibit an excellent long-range effect over a spectrum of many decades of wavelengths.

But acoustic waves are also well-suited for many sensing problems and are superior to the electromagnetic methods, particularly where transmission media (e.g. sea water) are involved which attenuate electromagnetic waves very strongly.

The electromagnetic spectrum which is in use for the various sensing methods—as partly described in the following chapters—is presented in Fig. 2 with the usual units and the usual designations of the various spectral ranges. Under the heading sensor types a representative sample of instrumental methods is enumerated.

Many sensor types are based on analysing the reflection of an artificial signal transmitted to the remote scene. These methods are often comprized under the designation "active methods". "Passive methods", on the other hand, are based on the emission of a type of radiation by the observed objects characterizing the media or their environmental states.

The natural radiation of the media can be of very different origin. Atomic and molecular gases at normal environmental temperatures e.g. exhibit characteristic line spectra due to the transitions between different quantum states in the visible, infrared and microwave parts of the spectrum. A very much different source of electromagnetic radiation is the natural radioactivity of e.g. Uranium, resulting in the gamma-radiation spectrum characteristic for minerals containing this element. A source of very low frequency radio-emission is the electric discharge during lightning in a thunderstorm.

A very broad spectral region is covered by the electromagnetic radiation due to thermal agitation in any medium. Regarding a non-transparent, non-reflecting ("black") body, the radiation behavior can be described by the Planck radiation law. Figure 3 represents the radiance of an ideal black body in units of power per Hertz bandwidth, which is emitted per square meter of radiating surface into one unit of solid angle. The effect of the temperature of the radiating surface is shown to be very pronounced in the infrared region (wavelength 10 microns or shorter at environmental temperatures), while the radiance is linearly dependent on the temperature in the microwave range. Most media encountered in nature are not "black" but—within the limited spectral widths of the particular sensors—gray i.e. their radiance is reduced by a factor smaller than unity. The spectral behavior (Fig. 3) enables small temperature differences of the various types of the terrestrial surface to be detected very sensitively by measuring the infrared (approximately 10 microns) radiance, but this sensitivity to temperature changes masks the radia-

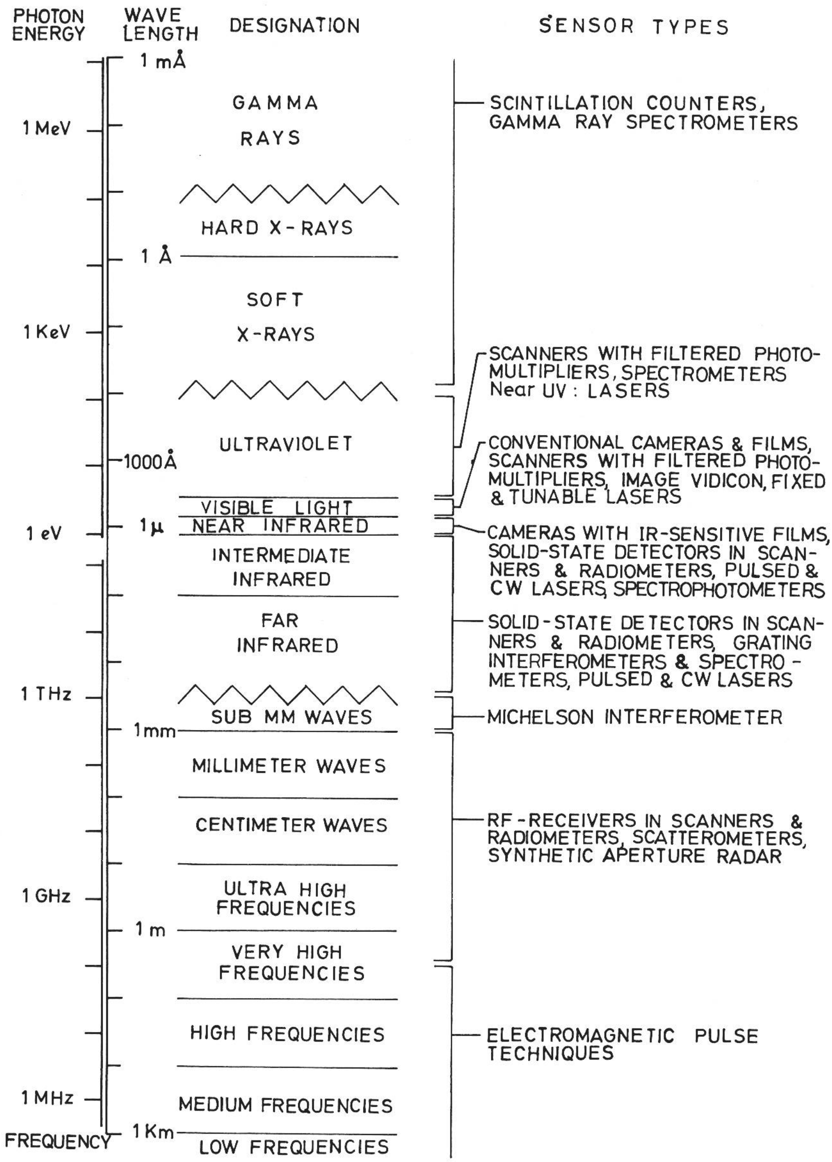

Fig. 2. The electromagnetic spectrum in units of wavelength, photon energy or frequency, whatever is appropriate. The various ranges of the continuous spectrum are named with their widely used designations. Different sensor types are required for the remote probing in the various ranges of the spectrum

tion differences due to the different emissivities, characterizing the type and composition of the media. In the microwave range (wavelength longer than 1 mm) on the other hand, slight changes of the emissivities (or albedos) are recognized very easily, but the sensitivity due to changes of the physical temperature is much less.