TECHNOLOGY TRENDS IN SPACEBORNE REMOTE SENSING INSTRUMENTS

Bill P. Clark
Computer Sciences Corporation
System Sciences Division
15245 Shady Grove Road
Rockville, Maryland 20850

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ABSTRACT

Multiple advances in remote sensing technology have been made available to the user community during the past decade. One survey of the future of remote sensing for NASA was performed in the early 1980's (Kostiuk and Clark 1984) and serves as the springboard for future technology needs. This paper discusses the critical parameters for new remote sensing instruments covering microwave, infrared, and visible regions of the spectrum. These parameters, projected in the earlier study, and the expansion and/or contraction of goals mentioned by NASA investigators due to technology problems, funding problems, and specific application problems for the data captured will be discussed.

INTRODUCTION

A survey of the state of the art in remote sensing was performed for NASA headquarters in 1983. (Kostiuk and Clark, 1984) Results of this early work were merged into a larger study (NASA 1984) designed to provide a projection of critical research required to meet NASA's mission requirements through the year 2000 A. D. The sensor survey was performed at the Goddard Space Flight Center (GSFC), using responses to a special questionnaire. Responses were gathered from the Jet Propulsion Laboratory, the Johnson Spacecraft Center, the NASA Langley Research Center and GSFC. Respondents included active government and contractor personnel from these centers and select members of the academic community. Each respondent was asked to identify the most critical areas of future research, identify the parameter or parameters that are currently felt to be the most critical for advancement of state of the art development of new instruments, and make projections relative to the future given multiple funding scenarios.

Response data were organized in terms of their applicability to generic sensor systems, subsystems, and components. Generic sensor systems were separated into active and passive categories within their operational wavelength or energy regions. The application and research areas associated with particular sensors and sensor types were also acquired.

This paper will summarize the result of the findings of the original study and expand it where possible to include state of the art technologies that have been developed during the past ten years. The first half of this paper will address instrument structure and applications. The second half will illustrate the critical parameter list currently available and published plans for the future using tabled data.

ACTIVE MICROWAVE SENSORS

Radar or active microwave sensors are used in a number of configurations to acquire information about the Earth and planetary surfaces. These include imaging, altimetry, sounding and scatterometry.

For surface imaging a Synthetic Aperture Radar (SAR) is usually required to be able to achieve high resolution (25 to 50 meters) from space. The Seasat SAR, SAR 78, Shuttle Imaging Radar, SIR-A (81), SIR-B (84), and the Venus Radar Mapper (88) provide a rich legacy of utility of this data type. Since the first paper was written the European Space Agency has launched a SAR, the Canadian Centre for Remote Sensing (CCRS) has initiated work on their instrument, and others around the world have either initiated programs or plan to have programs in the future that incorporate this sensor type. The NASA program has also continued. (Real aperture microwave systems are used for altimetry, sounding, and scatterometry.)

PASSIVE MICROWAVE SENSORS

Passive microwave sensors consist of two generic types - broadband radiometers, used to determine basic environmental parameters such as temperature, ocean windspeed, ice pack concentrations, polar ice types, water vapor, precipitation and gross atmospheric temperature profiles; and multi-channel-spectral radiometers

The principal subsystems of most microwave sensors are a collecting antenna, a hetrodyne receiver, and associated R.F. and digital electronics for data analysis. The hetrodyne receiver is composed of a local oscillator, a mixer, preamplifier and associated electronics. For spectrometer applications a spectral line receiver must also be used to provide the power spectrum of the mixer output (the IF frequency).

PASSIVE INFRARED SENSORS

Infrared sensors can be of three generic types including photometers, spectrometers, and imagers.

Photometers are broadband instruments capable of measuring thermal continuum radiation thereby permitting the study of the energy balance and surface composition of planets and the infrared brightness of astrophysical features.

Spectrometers, such as Fourier Transform Spectrometers, grating instruments, Fabry-Perot instruments or gas correlation spectrometers permit the measurement of molecular band and pressure broadened line profiles and thus the study of source composition and its pressure and temperature structure.

Imagers consist of detectors capable of spatial coverage through scanning or pushbroom techniques (linear arrays) or by staring techniques (area arrays) to map a region of interest.

Systems used for Earth sensing, atmospheric studies by solar or planetary surface radiance absorption spectroscopy and planetary surface studies are generally limited by the thermal background of the source. Thermal background of the instrument is of less concern.

Conceptual designs of most future sensor systems include multiple functions for the proposed instruments. Some degree of simultaneous spectroscopic, photometric and spatial information retrieval capability is normally attempted in the new designs

PASSIVE LASER SENSORS

Infrared hetrodyne spectrometers are typical of this sensor class. These sensors are analogous to millimeter wave hetrodyne radiometers. Infrared radiation from a source is combined with the output of a laser local oscillator on a mixer. The generated difference frequency (IF) is in the radio region. The spectral and intensity information contained in the infrared source radiation is thus shifted into the radio region where it can be detected and analyzed using RF or AOS spectral line receivers. The back end electronics (spectral line receivers) are very similar and in some cases identical to those used in the millimeter and submillimeter spectral regions. Since infrared radiation is of concern, optical quality telescopes are required to collect the source radiation.

These systems offer high spatial resolution. Being a coherent technique, the field of view is determined by the diffraction limit of the collecting optics. For a 10 micron source and a 3 meter diameter telescope the field of view is approximately one arc second.

If the absolute frequency of the local oscillator is known to a high accuracy hetrodyne detection can provide highly specific and accurate frequency measurements (one in one hundred million hertz for a carbon dioxide laser local oscillator. This facilitates species identification and permits gas velocity measurement to a few meters per second.

Gross spectral coverage is determined by the laser local oscillator. Gas lasers permit limited tunability about discrete laser lines. Tunable semiconductor diode lasers can be composition tuned to cover the 3 to 30 micron region of the spectrum and can be semicontinuously tuned over a range of 100 wavenumbers. The instantaneous total spectral bandwidth is determined by the photomixer and preamplifier frequency response and is presently larger than two gigahertz.

ACTIVE LASER SENSORS

Laser Radars or LIDARS consist of a laser, optics (telescope), a colocated detector, electronics for data conversion, and a data recording mechanism. The laser is operated in the pulsed mode. The emitted laser radiation interacts with the target (usually the upper atmosphere) and creates a backscatter or fluorescence that is collected by the optical system and measured by the detector and electronics combination. The collecting optical system is generally a Ritchey-Chretien type Cassegrain telescope which focus the return radiation onto a detector or detector array. Data are then recorded. Some systems use multiple lasers, others use multiple detector systems.

Systems developed to date fall into four generic categories. These include applications for resonance fluorescence, DIAL, Doppler and Laser Ranging. Resonance fluorescence and DIAL systems can be used for the study of atmospheric aerosol, molecular constituents, and atmospheric chemistry. Doppler LIDAR can be used to measure wind velocities and add to the study of global species transport and weather. Laser ranging systems can be used for ranging and altimetry measurements, adding to the study of the Earth's gravitational and magnetic fields, tectonic plate motion, and global geodesy.

Each system has unique requirements. As a result several types of lasers, detectors, mixers, and frequency doubler/frequency tripler subsystems have been developed to enhance signal detection and tailor the system to desired applications.

PASSIVE VISIBLE SENSORS

Passive visible systems are presently well developed. Needed advances lie mainly in larger lightweight collecting optics (telescopes) and large detector arrays. Large telescopes would permit greater light gathering capability and allow measurement of fainter and more distant astrophysical sources. Earth pointing systems will benefit from the same technology upgrades expected for systems used in astronomy.

Future visible sensors can be characterized as either mappers or cameras. Most of these will most likely be based on some sort of solid state detector array. Charge Coupled Devices (CCD), more than any other solid state camera system offer the capability of high resolution, high sensitivity, and low cost.

INSTRUMENT PARAMETER TABLES

The data presented in the tables that follow cover the best estimate of critical parameter values for active microwave, passive microwave, infrared, infrared detectors, passive laser systems, active laser systems, and passive visible systems. The last column in each table has been reserved for inputs relative to whether or not these parameter values have been met using today's technology. It was felt important to insert this column to indicate that some technologies are moving forward faster than others. When a YES answer is presented in this column it indicates that there is widespread knowledge that the goals for the year 2000 have been met today. When a TBD is presented in this column it indicates that some or most of the goals have been attained yet instruments have not yet been operationally tested. This final definition is in conformance with the NASA standard definition of instrument development levels. These levels are given as follows:

LEVEL 1:	Basic Principles Observed and Reported
LEVEL 2:	Conceptual Design Formulated
LEVEL 3:	Conceptual Design Tested Analytically or Experimentally
LEVEL 4:	Critical Function/Characteristic Demonstration
LEVEL 5:	Component/Breadboard Tested in Relevant Environment
LEVEL 6:	Prototype/Engineering Model Tested in Relevant Environment
LEVEL 7:	Engineering Model Tested in Space

SUMMARY

The data presented in this review have of necessity been abbreviated to illustrate the gross trends forecast by the respondents. For example, due to space limitations, no details regarding different areas of materials research required to achieve breakthroughs in component performance have been provided. The relationship between these research activities and projected system and subsystem capabilities are presented in the two references that follow. Data pertaining to unique problems expected in allied fields of communications and data processing are also summarized in these papers.

All data presented supports the fact that there has been a notable trend in the past few years to replace stand alone systems that perform a single function with larger, multifunction systems capable of some degree of autonomous operation and on-board decision making. In addition, most new systems are larger, heavier, and more power consumptive than those supported by past free flying spacecraft. When the original paper was completed this was a natural result of the then existent future emphasis on large orbiting spacecraft such as the polar platform and the space station. Since the original paper was completed multiple reviews of these programs have led to divergent opinions relative to how best to implement the new technologies as they evolve. Decisions made in this area will be driving factors for the future of new instrumentation.

REFERENCES

NASA SPACE SYSTEMS TECHNOLOGY MODEL: SPACE TECHNOLOGY TRENDS AND FORECASTS, 1984, NASA/OAST, Washington, D. C.

T. Kostiuk and B. Clark, 1984, SPACEBORNE SENSORS (1983-2000 A.D.): A FORECAST OF TECHNOLOGY, NASA Technical Memorandum 86083, Goddard Space Flight Center, Greenbelt, Md. 20771

Active Microwave	SOA VALUE	2000 VALUE	2000 VALUE MET (Y/N)
Synthetic Aperture Radar 600 cm - 3 cm Resolution			
Planetary	100 m	50 m	NA
Earth Orbit	25 m	10 m	yes
Swath Width	220 km	400 km	TBD
Multipolarization	NA	HH,HV,VH,VV	TBD
Multifrequency	Dual (L,X)	Multiple L,S,C,X, Ku	Yes
Signal Amplitude Precision	3 dB	2 dB	Yes

TABLE 1. CRITICAL PARAMETERS FOR ACTIVE MICROWAVE

Passive Microwave 21 cm - 0.01 mm	SOA VALUE	2000 VALUE	2000 VALUE MET (Y/N)
Broadband Radiometers for Earth Sensing (21-0.15 cm)			
Receiver Power	10 W	< 5 W	TBD
Receiver Weight	8 kg	< 1.0 kg	yes
Sensitivity	0.6 K	0.4 K	TBD
Beam Efficiency	95%	98 %	yes
Footprint	2-100 km	50 m	TBD
Millimeter and Submillimeter Heterodyne Radiometers			
5 mm Radiometer Noise Temperature	1000 K	50 K	TBD
1 mm Radiometer	500 K	100 K	TBD
0.5 mm Radiometer	1000 K (Narrow Band) 50,000 K (Broad Band)	200 K (Narrow Band) 500 K (Broad Band)	TBD
0.10 mm Radiometer	5000 K (Narrow Band) 100,000 K (Broad Band)	1000 K (Narrow Band) 5000 K (Broad Band)	TBD
Millimeter Wave Radiometer Noise Temp. (K)			TBD
30 GHz	50	10	
100 GHz	200	20	
300 GHz	2000	100	

Table 2. Passive Microwave (1 of 2)

Passive Microwave Systems (2 of 2)	SOA VALUE	2000 VALUE	2000 VALUE MET (Y/N)
Millimeter Wave Radiometer			
Noise Temperature (K)			
30 GHz 100 GHz 300 GHz	50 200 2000	10 20 100	TBD
Submillimeter Spectrometer Noise Temperature (K)			
300 GHz 1000 GHz	2000 100,000	100 8000	TBD
Submillimeter Laser Heterodyne Spectrometer			
Noise Temp. (K) at 690 GHz Laser Power (mW) Laser Operating Frequency (GHz)	6000 10 3000	500 100 10,000	YES

Table 2. Passive Microwave (2 of 2)

Passive Infrared	**SOA VALUE**	2000 VALUE	2000 VALUE MET (Y/N)
Multispectral Linear Arrays (0.4 - 12.5) microns			
Earth Sensing Systems			
IFOV (m)	30	10	YES
Pixels per Scene	3×10^{8}	2×10^{9}	TBD
Acquisition Data Rate (Mbs)	85	500	TBD

TABLE 3. INFRARED SYSTEMS

Infrared Detector Technology (1 - 1000) microns	SOA VALUE	2000 VALUE	2000 VALUE MET (Y/N)
Discrete Detector Noise Equivalent Power (NEP) $WHz^{-1/2}$			
InSb (5 micron)	1×10^{-16}	1×10^{-17}	TBD
Si:X (15 micron)	3×10^{-16}	5×10^{-19}	TBD
Ge:Ga (100 micron)	3×10^{-17}	1×10^{-19}	TBD
Monolithic Arrays (1 - 12 microns) Elements per Focal Plane	500 (LWIR) 5000 (SWIR)	2000 10,000	NO
Detectivity cm $Hz^{1/2}$ W^{-1} HgCdTe 8-12 micron	5×10^{11}	2×10^{12}	TBD
InSb 5 micron	5×10^{12}	10^{13}	

TABLE 4. INFRARED DETECTOR TECHNOLOGY

Passive Laser Systems	SOA VALUE	2000 VALUE	2000 VALUE MET (Y/N)
IR Hetrodyne Spectrometer 3-30 microns			
10 micron laser power per mode	400 micro Watts	10 milliWatts	TBD
28 micron laser power per mode	80 Microwatts	500 Microwatts	TBD
Operating Temp. (K) 10 micron 28 micron	 10-70 N/A	 70-100 40-70	TBD
Photomixer Bandwidth (GHz) 10 micron 28 micron	 1.5 0.5	 5 1	TBD
Photomixer Efficiency (%) 10 micron 28 micron	 40 N/A	 60 50	TBD

TABLE 5. Passive Laser Systems

ACTIVE LASER SYSTEMS (0.2-12) microns	**SOA VALUE**	2000 VALUE	2000 VALUE MET Y/N
CO2 Laser Dial 9-12 microns NEP ($WHz^{-1/2}$) Laser Pulse Energy	10^{-12} 100 mJ	10^{-16} 1 J	Yes
Transition Metal DIAL 1.5-2.3 microns Pulse Energy	100 mJ	500 mJ	TBD
Dye Laser DIAL 0.28-1.06 microns Pulse Energy PRF	300 mJ 10 pps	1 J 40 pps	TBD
Solid State Laser DIAL 0.7-0.8 microns Peak Power (W)	3×10^{6}	10^{10}	TBD
Eximer Laser LIDAR 0.2-0.4 micron Pulse Energy Coverage of 200 to 400 nm spectral range Efficiency Shots per Laser Lifetime	3 J 10 % 2 % 10^{7}	25 J 100 % 4 % 10^{8}	No
Doppler LIDAR 9-11 microns PRF (Hz)	1	100	No
LIDAR Ranging System 0.4-0.8 micron Timing Precision Ranging Error	5×10^{-11} 10 mm	2×10^{-13} 0.5 mm	YES

Table 6. Active Laser Systems

Passive Visible Systems 0.4-1.1 microns	SOA VALUE	2000 VALUE	**2000 VALUE MET (Y/N)**
CCD Detector Arrays			
Mosiac	10^{6} elements	10^{7} elements	TBD
Single Chip	5×10^{5} elements	10^{7} elements	TBD
Quantum Efficiency	10 % (6 microns)	60 % (4 microns)	TBD
Noise (electrons)	15	2	TBD
Readout Rate pixels/sec	10^{6}	10^{9}	TBD

Table 7. Passive Visible Systems