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Optical infrared remote sensors

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Abstract. Various kinds of remote sensors, active and passive, covering a significant part of the electromagnetic spectrum from ultraviolet to microwave regions have been developed for observation of earth for the purpose of resource survey. Several of the widely used remote sensors (in the visible and infrared region) beginning from photographic cameras to the modern-day linear imaging self-scanning sensors have been described with reference to the state-of-the-art, critical parameters, performance limitations etc. User requirements with regard to various system parameters of the remote sensors have been analysed. Some future trends in the development of remote sensors for spaceborne applications have been touched upon.

Keywords. Remote sensors; optical infrared sensor; photographic camera; television camera; return beam vidicon; spectral response; optical mechanical scanner

1. Introduction

Remote sensing is the science of making inferences about material objects from measurements, made at a distance, without coming into physical contact with the objects under study. When viewed in this context, remote sensing covers various disciplines from astronomy to laboratory testing of materials. However remote sensing is currently used more commonly to denote identification of earth features by detecting the characteristic electromagnetic radiation that is reflected or emitted by the earth surface. Electromagnetic radiation extending from the ultraviolet to the far-infrared and microwave regions provides the greatest potential in the context of earth resources survey.

Sensors which sense natural radiations, either emitted or reflected from the earth, are called passive sensors. It is also possible to produce electromagnetic radiation of a specific wavelength or band of wavelengths and illuminate a terrain on the earth's surface. The interaction of this radiation with the target could then be studied by sensing the scattered radiation from the targets. Such sensors which produce their own electromagnetic radiation are called active sensors. Again sensors (active or passive) could be either 'imaging' like the camera, or 'non-imaging' like the radiometer. The imaging sensors can again be categorised into (i) instantaneous imaging sensors and (ii) line scan imaging sensors. In instantaneous imaging sensors, the area under the field of view of the sensor is imaged instantaneously, and such an image is then recorded electronically or on a photographic film. Typical examples of this type of sensors are photographic camera, TV camera etc. In a line scan sensor, the sensor records one picture element (instantaneous field of view—IFOV) at a time. A line is generated by mechanically or electronically scanning the IFOV in one direction. The motion of the platform produces successive scan lines, thus generating a two-dimensional image. Typical examples are multispectral scanners and linear imaging self scanning (LISS) sensors. The technology of sensors operating in the microwave region is quite different from those operating in the shorter wavelength. Based on this it is convenient to classify sensors as optical infrared (OIR) sensors and microwave sensors. In this paper we deal with various types of OIR sensors, its current status and future trends. We will also deal with the imaging sensors, since they are most widely used for remote sensing applications.

2. Requirements of remote sensors

Before going into the details of various remote sensors it is worth reviewing the basic requirements of these sensors from the point of view of resources survey applications. It is now well established that for improved information extraction it is essential to have imagery taken in more than one spectral band. Apart from the multispectral capability the user would like to optimise various image parameters to his maximum advantage. The major sensor parameters which have bearing on optimum utilisation of data include the following.

(a) Spatial resolution—which essentially defines the capability of the sensor to discriminate the smallest object on the ground. The resolution quoted in various imaging sensors is geometric resolution. However the usable resolution is a complex function of various instrument parameters like the modulation transfer function (MTF), signal-to-noise ratio etc. In order to compare different sensors the resolution is sometimes referred with respect to 50% MTF point.

(b) Spectral resolution—the spectral bandwidth with which the imagery is taken; narrow bandwidth is expected to make certain features more prominent.

(c) Number of spectral bands—the optimum number of bands required to extract a certain information is an important parameter. In addition to the number of bands, it is also important to know at what region of the electromagnetic spectrum one is acquiring the data. Depending upon the spectral region the detector technology changes and hence has an impact on overall sensor system design.

(d) Sensitivity—which essentially gives the capability to differentiate the spectral reflectance/emittance between various targets. This is normally referred to as noise equivalent reflectance (NE$\Delta\rho$) or differential temperature that can be measured (NE ΔT) in the thermal band.

(e) Dynamic range—the minimum to maximum reflectance that can be faithfully measured.

In addition to the above basic parameters, the sensor should produce imagery with geometric fidelity.

All the above requirements are inter-related. Trade-off between various parameters and certain compromises will be required to realize a sensor system. Let us now consider various types of sensors which are generally used for resources survey.

3. Photographic cameras

Photographic cameras are the oldest and probably the most widely used sensors. They have been successfully used from aircraft, baloons, manned and unmanned spacecraft. Though there are different types of camera, frame cameras have been most commonly used as remote sensors. A frame camera consists of the following.

(a) A magazine which can hold a roll of the photographic film on the supply and takeup spools, and can invariably be detached from the camera.
(b) A drive mechanism to transfer the film from the supply spool to the take-up spool between exposures. The film is held stationary during exposure so as to keep the image distortion to the minimum; the film is held flat against the locating plate at the focal plane. A vacuum system usually ensures this.
(c) A cone which holds the lens assembly at the precise distance from the image plane to get the correct focus at the image plane.
(d) A properly corrected lens assembly.
(e) A shutter mechanism to expose the film; this is incorporated at the focal plane or within the lens assembly.

Metric cameras used for cartographic applications have fiducial markers and reseau markers exposed on the film simultaneously with the ground scene, to take care of geometric distortion and location of principle points. Also extensive information regarding the aerial flight, time, camera data etc can also be recorded alongside the film in each image.

Films are available with different spectral sensitivity and resolution. The response of black and white film is about 0·4 to 0·7 μ. For infrared imagery films with response extending upto 0·9 μ are available. Infrared false colour film has been extensively used for remote sensing. The three emulsions are sensitised to green, red and infrared radiation instead of the usual blue, green and red wavelength. Thus when the film is exposed the resulting colour display is different from the natural colours and hence called false colour.

Among frame cameras, multiband camera plays the most important role for resources survey. Multiband camera enables simultaneous photography of a ground scene in more than one spectral band. This can be achieved generally by using different single band cameras and very accurately aligning them so that all the images are geometrically registered. In this case each band will have its own lens, film magazine and the appropriate filters. Alternately multiple optics transfers images in different spectral bands on to a single large photographic film.

Multispectral photographic camera flown in *Skylab* manufactured by Itek Corporation is one of the best examples of multiband camera. The system consists of 6 precisely matched lenses rigidly mounted on the camera body. Each lens is specifically matched in focal length to the proper spectral band and has its own film magazine, shutter and control. The lenses are optically aligned with one another. Using different filter and film combination, 6 lenses record information on black and white film in separate regions of the visible and near infrared spectrum. The other two lenses record colour information: one covers the normal colour and the other false infrared colour.

In the I^2S, airborne multiband camera (manufactured by International Imaging

System, USA) (Ross 1973) four separate lens-filter assemblies form four 89 × 89 mm images of the same area on a 240 × 240 mm film.

The important factors which determine the performance of the camera are (a) lens resolution (b) film resolution (c) film flatness and focal plane location (d) accuracies of image motion compensation. With modern computer-aided design lens could approach diffraction limited performance. High definition aerial film exceeding 300 4/mm resolution are available. Different methodologies of image motion compensation have been developed to reduce blurr due to motion of the sensors during the exposure time. All these factors make the camera an excellent sensor with high geometric fidelity and resolution. In addition photography with overlap enables one to have a stereoscopic view of the scene.

Latest in the development of photographic cameras may be the large format camera to be placed on-board the Space Shuttle-17 (Doyle 1978). The camera is being developed by Itek's optical division under a NASA contract. Each picture frame will cover about 165 × 335 km from the 220 km orbit and will have a spatial resolution of about 11 m. Resolution of terrain height will be about 6 m. Different film-filter combination can be used with the camera. Each negative of a picture frame measures 250 × 460 mm. Upto 1200 m of film can be stored on the single supply spool, sufficient to produce about 2,300 frames. The camera will weigh about 320 kg.

In principle, the earth could be mapped by just two Space Shuttle missions in polar orbit. However due to cloud cover, about 3 to 4 flights may be required to cover the globe completely. Once this is operational, having terrain height as well as an outline, cartographers will be able to produce accurate topographic maps.

As a remote sensor, photographic cameras have a number of limitations. Cameras have a limited spectral response extending only upto 0·9 μ. The middle IR and thermal IR, regions which are of great interest cannot be covered with photographic cameras.

The dynamic range of the camera, which essentially depends on the film is also limited.

Reproducibility of the quality of the imagery depends on the processing of film which unless controlled very carefully, will be difficult to compare different images quantitatively.

The data, since not available directly in the electronic form, is not immediately amenable to digital processing which is essential when one wants a large throughput of resources information. In addition, for unmanned spacecraft the film has to be ejected out for recovery which complicates the system.

4. Television cameras

The first electronic system to take imagery of earth from space, is television camera. Starting from TIROS-1 in 1960 vidicon cameras were used in a number of meteorological satellites for routinely viewing the earth for world's weather studies. The early TIROS cameras used 12·7 mm (1/2 inch) slow scan vidicon, at 400 TV lines per frame. The improvement of the TV camera depends on the improvement of the basic imaging tube. The technology of TV tubes has advanced during the past decade and we now have TV cameras atleast an order of magnitude better in resolution and sensitivity.

In the vidicon camera an optical system is made to focus the ground image on to the photoconductive surface. The incident photons on the surface vary the conductivity of the surface locally according to the light intensity. An electron beam is made to scan the photoconductive surface from the rear side. The resulting beam current will be proportional to the conductivity of the photoconductive surface (and hence the intensity of light) and the signal is further amplified and recorded or transmitted.

In the case of return beam vidicon (RBV) the signal is derived from the depleted electron beam, which is reflected from the photoconducting surface, which is further amplified by a multistage electron multiplier.

The best example of high resolution TV cameras operated in space for resources survey is the return beam vidicon used in the LANDSAT series (NASA 1976). Essential characteristics of the LANDSAT camera are given in table 1.

The Indian experimental remote sensing satellite *Bhaskara-I* and *II* carried a two-band television camera system. Of the two bands one operated in the 0·54–0·66 μ region and the other in the 0·75–0·85 μ wavelength region (Joseph 1983). Each picture frame covers about 400 × 400 km^2 with a spatial resolution of about 1 km. Table 2 gives camera specifications.

Typical imaging tubes used in spaceborne high resolution cameras include return beam vidicon, image dissector tube, secondary electron conduction tube etc. Details of operation of these tubes are well documented and will not be dealt here.

The limitations of TV camera system for resources application include—

(a) *Registered multispectral imaging:* Multispectral imagery can be produced as in LANDSAT or *Bhaskara* by using separate camera tubes for each band and selecting the spectral band using appropriate filters. The principal disadvantage for such a system is the difficulty of registration in all the bands. Even if one can optically align them

Table 1. LANDSAT RBV camera parameters

Spectral bands (LANDSAT 1 & 2)	0·475–0·575 μ 0·580–0·680 μ 0·698–0·830 μ
Image size	1 inch^2
Field of view	15·9°
Exposure	4 to 16 ms selectable in five steps
Active horizontal scan lines	4125
Dynamic range	30 to 1
Signal-to-noise	33 dB

Table 2. TV camera payload specifications

Sensor type	Slow scan vidicon coupled to an image intensifier
Imaging lens	F/no. 1·9 Focal length 18·46 mm Field of view 49·37°
Spectral channels	Camera-1: 0·54–0·66 μ Camera-2: 0·75–0·85 μ
Picture frame	341 × 341 km^2 for a 525 km altitude
Ground resolution	About 1 km
Exposure control	1, 1·5, 2 ms selectable by ground command
Power	22·5 W average
Weight	44 kg

accurately, difference in electron optics and possible drift in the scanning electronics produce misalignment. For large number of spectral bands, the total system becomes very cumbersome, with large size and volume.

The alternate way of obtaining multispectral imagery is to use a single tube. Though a number of schemes for multispectral imaging using a single TV tube have been developed, at present they are not being planned for any future resources survey satellites.

(b) *Spectral response*: The usual photoconductor for vidicon, ASOS (antimony trisulphide osysulphide) has a response from 0·4 to 0·75 μ with peak sensitivity around 0·6 μ. The sensitivity could be extended beyond 0·75 μ by using either photoemissive surface as the input window (as in SEC and image dissector tubes) or by using silicon target.

However for resources survey the near-IR region extending upto few microns is very useful. The presently available camera tubes are not able to cover such a large range.

Recently a new type of camera tube (pyricon) sensitive in the thermal IR region (8–14 μ) has been developed. However the resolution capability of these devices is very low for use in spaceborne imaging system.

(c) *Resolution*: The LANDSAT RBV has a resolution of 45 cy/mm at 50 % MTF. To take an imagery with the same image size and a ground resolution of 20 m/TV line will require an improvement in resolution by a factor or two or have a tube of double the format size. Large format TV tubes are under development.

Other limitations of TV tubes include poor dynamic range, radiometric accuracy and geometric distortions. On the whole it is unlikely that TV imaging systems will be able to satisfy the user requirements of multispectral imaging. It is worth noting that in LANDSAT 3, the RBV is used in a panchromatic mode.

5. Optical mechanical scanners

Most of the limitations seen with photographic and TV imaging system are overcome in optical mechanical scanners, though they have their own limitations. It may be interesting to note that early attempts (1940) to translate variations in scene brightness into electrical video signals utilised optical mechanical scan techniques. These 'mechanical scanning television systems' quickly became obsolete with the development of electron beam scanning tubes such as vidicon.

Figure 1 shows the principle of operation of a line scanner. The radiation emitted (or reflected) from the scene is intercepted by a scan mirror, which diverts the radiation to a collecting telescope. The telescope focusses the radiation to a detector. In the normal case, the scan mirror is inclined 45° to the optical axis. When the scan mirror is rotated about the optical axis, the field of view of the telescope sweeps out a circle in a plane normal to the scan mirror rotation (that is, the optical) axis. Thus, by the scan mirror rotation, radiation is received and measured from a continuous line of length corresponding to the total scan angle. If such an instrument is mounted on a moving platform (aircraft or spacecraft) with the optical axis parallel to the platform motion, the motion of the platform produces successive scan lines, giving a contiguous imagery.

In the case of a multispectral scanner, the energy collected by the telescope is

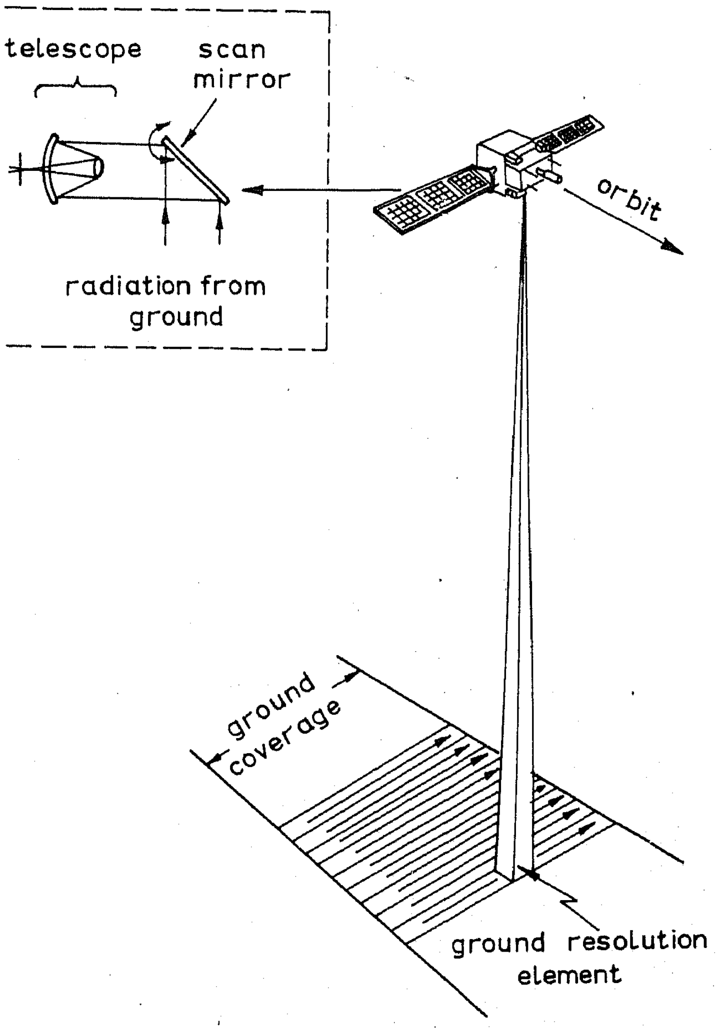

Figure 1. Geometry of a line scanner

channelled to a spectral dispersing system (spectrometer) to be registered in different spectral bands. Figure 2 gives the functional block diagram of a multispectral scanner.

Detectors are selected according to the spectral region to be covered. In the visible region, both photomultipliers and photodiodes have been used as detectors. The

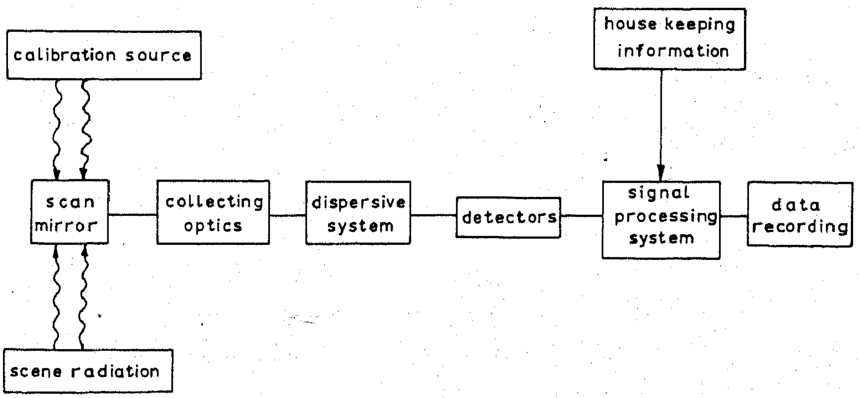

Figure 2. Functional block diagram of MSS system

photodiodes cover wavelengths extending from 0·4 to about 1·1 μ. A number of detectors, with the required sensitivity, operate in the near and far-infrared region. Of these, the most commonly used is the mercury cadmium telluride (MCT). With the right proportion of mercury and cadmium telluride and operating temperature, MCT can operate from visible wavelengths to 16 μ. Detectors operating beyond a few microns are generally cooled to increase the signal-to-noise ratio.

The MSS instrument carries a number of calibration sources for a quantitative measurement of the radiance collected. The calibration sources include temperature-controlled black bodies for the thermal region and quartz halogen lamp for the ultraviolet to the near-infrared region. Sunlight is also sometimes used as reference.

Typical examples of airborne MSS include the 11-channel M^2S developed by Bendix (USA) and the six-channel MSS developed at ISRO (India).

M^2S multispectral scanner which uses a Dall-kirkham telescope in its front end after a rotating scan-mirror assembly. The focal length of the telescope with the aperture stop at the focal plane determines the IFOV of the scanner, which is 2·5 mrad. The output from the scan mirror/telescope falls on a dichroic mirror which reflects the thermal IR part of the incoming radiation to a liquid nitrogen cooled HgCdTe detector assembly. The rest of the radiation is transmitted to a diffraction grating through a collimating lens assembly. The diffraction grating disperses the energy into ten components in the visible and near-IR region and a reimaging lens focusses each component onto the relevant silicon detector. The detector output is pre-amplified, digitised, pre-processed and recorded on a high density digital tape recorder.

ISRO MSS has a combination of beam splitters and filters for spectral selection (Joseph & Kamat 1978). This has the advantage that any set of desired spectral bands can be selected with appropriate filters and detector combination.

LANDSAT-1 MSS has four spectral bands in the 0·5 to 1·1 μ region. LANDSAT-2 and 3 MSS have an additional band in thermal IR. MSS on-board LANDSAT consists of an RC telescope with 23 cm aperture (Lansing & Cline 1975). The cross-track scan is achieved by an oscillating mirror at a frequency of 13·6 Hz. In order to reduce the scan rate (thereby to increase the dwell time) 6 detectors are used in one band, for the visible and near-infrared. Thus for each scan, 6 lines are generated per spectral band. The IFOV is defined by the ends of optical fibres arranged in a matrix of 6 × 4 at the focal plane of the telescope. The light conducted through the fibres are detected by photomultipliers/photodiodes with appropriate filters. The fifth band covering the thermal-infrared is relayed from the telescope focal plane and reimaged on to a mercury cadmium telluride detector which is cooled by a radiation cooler. The detector outputs are suitably amplified multiplexed and either transmitted or recorded on a high-density tape recorder. MSS provides a spatial resolution of about 80 × 80 m with a swath of 185 km from the 904 km altitude. The important parameters of MSS are given in table 3.

The limitations of line scanners include:-

(a) *Spatial resolution*: Improvement of spatial resolution is inter-dependent on various parameters of scanner sub-systems, and orbit. To illustrate this, a case study for improving the LANDSAT MSS resolutions by a factor of 4 is described in terms of its impact on the number of detectors, scan rate, and optics aperture (table 4). This clearly indicates the number of detectors, and optics size (hence weight) increase much faster than the resolution improvement.

(b) *Spectral resolution*: Decrease in spectral resolution directly decreases the input

Table 3. LANDSAT MSS specifications

Optics	– 22·9 cm Ritchy-Chretien with 10·16 cm secondary F/3,8
Scan method	Oscillating mirror ± 2·9° at 13·6 Hz with 45% active scan
No. of bands	5
No. of detectors	6 per band for bands 1 to 4, and 1 for band 5

Performance characteristics/detectors

Band	Wavelength (μ)	S/N (mw/cm^2/sterad)	Detector
1	0·5–0·6	113 at 2·48	PM
2	0·6–0·7	86 at 2·00	PM
3	0·7–0·8	72 at 1·8	PM
4	0·8–1·1	123 at 4·60	Si PD
5	10·4–12·5		HgCd(Te)

IFOV	86 μrad (bands 1–4) 26 μrad (band 5)
MTF	0·42
Band-to-band registration:	50 m (with ground processing)
Data rate	15 MBPS
Weight	64 kg
Power	55 W
Calibration	Halogen lamp, skylight
Quantisation	6 bits

Table 4. Parameter variation of LANDSAT MSS to improve resolution by a factor of 4, but keeping the same signal-to-noise ratio (S/N)

Type of detector	Present			Case 1			Case 2			Case 3		
	D	N	S	D	N	S	D	N	S	D	N	S
PM	23	6	13·6	23	1536	0·24	368	6	54·5	184	24	13·6
PD	23	6	13·6	23	24576	0·013	184	6	54·4	130	24	13·6

D: Aperture diameter (cm); N: no. of detectors/band; S: scan frequency (Hz)
PM: Photomultiplier as detector, PD: Photodiode as detector
Case 1 D kept same as the present value, but N changed for required S/N and scan frequency for contiguous scan
Case 2 N kept same as the present value, but D changed for required S/N
Case 3 Scan frequency kept same as the present value, but D & N changed to get same S/N and contiguous scan.

radiance at the detector and hence demands detectors with increased sensitivity to keep satisfactory S/N ratio. Also the number of spectral bands increases the complexity of the system in addition to the higher data rate.

(c) *Sensitivity*: This again depends on the detector and pre-amplifier electronics and this is dictated by the overall S/N and dynamic range requirement.

The best improvements one can achieve with the line scanners have been probably

Table 5. Thematic mapper specifications

Optics	40·6 cm Ritchy-Chretien F/6
Scan method	Oscillating mirror at 7 Hz with 85% scan efficiency
No. of bands	7
No. of detectors/band	16 for bands, 1–5, 7 4 for band-6

Performance characteristics/detectors

Band	Wavelength(μ)	NE	Detectors
1	0·45–0·52	0·8%	Si PD
2	0·52–0·60	0·5%	Si PD
3	0·63–0·69	0·5%	Si PD
4	0·76–0·90	0·5%	Si PD
5	1·55–1·75	1·0%	In Sb
6	10·4–12·5	0·5k (NEΔT)	HgCd(Te)
7	2·08–2·35	1·4%	In Sb
IFOV:	43·0 μrad for 1–5, 7 170·0 μrad for 6		
MTF	0·35		
Band-to-band registration:		6 m	
Calibration		Halogen lamp	
Quantisation		8 bits	
Data rate		85 MBps	
Weight		243 kg	
Power		300 W	

achieved with thematic mapper (TM) carried on-board LANDSAT-4 (Lansing *et al* 1979). TM provides 7 narrow spectral bands covering visible, near infrared middle infrared and thermal infrared spectral regions. TM provides 30 m resolution in the visible-, near- and middle-infrared bands and 120 m resolution in the thermal-infrared from the orbiting altitude of 705 km. Apart from the improved spatial and spectral resolution, TM provides a factor of two improvement on the radiometric sensitivity, for which TM uses 16 detectors per band (against 6 per band in MSS) and weight and power consumption about 4 times that of MSS. The important specifications of the thematic mapper are given in table 5.

6. Linear imaging self-scanning sensor (LISS)

In this system, the basic sensor is a linear array of solid-state detectors. The array may be made of photodiodes, phototransistors or charge-coupled devices (CCD). This type of sensor is possible due to the development of the metal oxide semiconductor (MOS) technology.

In a remote sensor using LISS, the optics focusses a strip of terrain in the cross-track on to the sensor array. The image from each detector is stored and shifted out sequentially to get a video signal like one scan line in the TV camera. The motion of the spacecraft produces successive scan lines, thereby giving a two-dimensional picture. This is illustrated in figure 3. The resolution primarily depends on the number of photodetectors available in a linear array and the required swath.

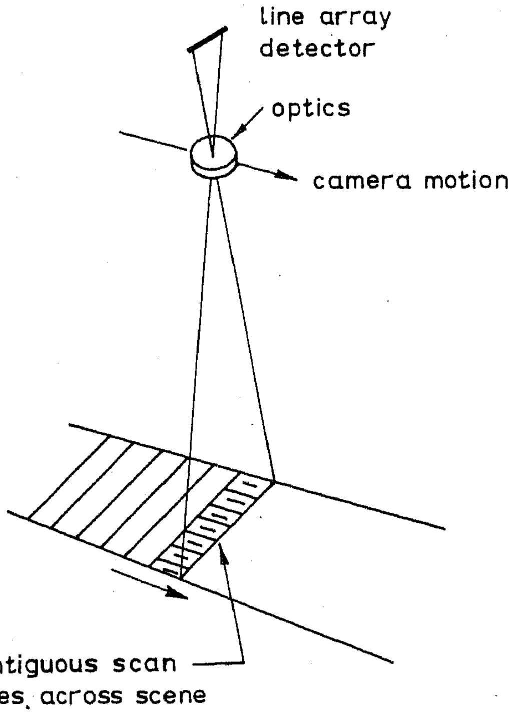

Figure 3. Illustration of LISS operation

The modular opto-electronic multispectral sensor (MOMS-I) carried on the space shuttle-7 is the first multispectral CCD camera to take imagery from space. The MOMS-I has two narrow spectral bands centred around 0·6 to 0·9 μ with a bandwidth of 0·25 and 0·75 μ respectively. Four CCD arrays each with 1728 elements have been optically butted to produce 6912 elements per band. The camera produces a total field of view of about 26·2° and an IFOV of 67·5 μrad. From the shuttle flight orbit it gives a spatial resolution of about 15 m. The follow-on MOMS is expected to have additional spectral bands in the middle infrared.

The French Space Agency (CNES) is developing an earth observations satellite system (SPOT) which carries a CCD-based camera (Paraldi 1978). The camera can be operated either in the multispectral mode or in panchromatic mode. In the multispectral mode it gives a spatial resolution of 20×20 M^2 in three spectral bands and in the panchromatic mode 10×10 M^2 from a flight altitude of 809 km. The instrument essentially consists of a front end mirror which can be rotated so as to view off nadir, a folded catadioptric telescope, three dichroic prisms for the spectral separation, and beam splitter prisms, one for each band for optical butting.

The Indian remote sensing satellite (IRS) to be launched in 1985–86 will carry a set of 4 band CCD cameras (Kasturirangan 1983). Two types of cameras are envisaged for IRS-1 camera with a resolution of about 73 m and a swath of about 148 km and the other with a resolution of about 36·5 m and a swath of about 74 m. Both the cameras provide 4-band imaging in the 0·45 to 0·86 μ region. Two cameras with 36·5 m resolution are used to provide a combined swath of 145 km. The major parameters of the camera system are given in table 6.

Japan is developing a CCD based camera system for their marine observation satellite (MOS) (Tsuchia 1981). A number of other camera systems using CCDs are being planned

Table 6. Design goals of IRS camera

	LISS-I (LRC)	LISS-II (MRC)
Geometric resolution (m)		
(from 904 km)	73	1/2 LRC RES
Swath (km):	148	74
Spectral bands (μ)		
1.	0·45–0·52	0·45–0·52
2.	0·52–0·59	0·52–0·59
3.	0·62–0·68	0·62–0·68
4.	0·77–0·86	0·77–0·86
Quantisation (bits)	7	7
Signal-to-noise ratio	128	128
Sensor MTF		
Band 1	0·40	0·40
Band 2	0·40	0·40
Band 3	0·30	0·30
Band 4	0·20	0·20
Band-to-band registration (pixel):	± 1/4	± 1/4

by NASA for their future missions. These include the stereo camera for automated satellite mapping system (MAPSAT), multispectral resources sampler (MES) etc. The basic limitation of CCD imagers currently used is that they are available only in the 0·4 to 1·1 μ region. Considerable research is being carried out to produce arrays in the middle-infrared and thermal-infrared. By the end of the century it is likely that the linear imaging sensor with adequate number of elements covering useful electromagnetic spectrum from visible upto thermal IR will be available for use. They can revolutionise the capability of multispectral imaging from space.

7. Future advances in spaceborne remote sensors

An advanced version of remote sensor system under study is a large earth survey telescope (LEST) for observations from synchronous earth observation satellite (SEOS) (Young 1975). Remote sensing from synchronous altitude promises to yield many advantages over observations from low altitude, especially for detection and measurement of highly transitory phenomena and for frequent repetitive coverage. The major difficulty in realising such a sensor is the requirement of high instrumental resolution so as to provide imagery with reasonable ground resolution from the synchronous altitude. The LEST currently planned is a 1·5 m diameter telescope. The resolution envisaged ranges from 100 M in the visible to 800 M in the infrared region, and covers the spectral region from 0·5 to 13 μ. The system is likely to be realised with a combination of CCD arrays and scan mechanism. The SEOS when realised will provide the remote sensor user with unique data of reasonable spatial resolution, wide spectral coverage and repetitive monitoring.

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