Sensors and Platforms for High Resolution Imaging for Large Scale Mapping Applications
- Indian Scenario
(invited paper)

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1. Introduction

In the area of Satellite based remote sensing in the past, the first generation Satellites IRS-1A and 1B were designed, developed and launched successfully during 1988 and 1991 with multi-spectral cameras with spatial resolution of 72.5 m and 36 m respectively. Subsequently, the second generation remote sensing satellites IRS-1C and 1D with improved spatial resolutions of 70 m in multi-spectral and 5.8 in panchromatic bands and a wide field sensor with 188 m resolution and 80 km swath, have been developed and successfully launched in 1995 and 1997 respectively. These satellites have become the principal components in the National Natural Resource Management System and the data is being used in various applications, viz., agriculture and soil, land form and land use studies, water resource, forestry, drought and flood monitoring, cartography, town planning and coastal zone monitoring. Specially IRS-1C/1D data are being used for cartographic and town planning applications up to 1:10,000 scale. These satellites also provide stereo pairs of imageries to get height information to an accuracy of approximately 10 meters.

With the above scenario, India has a lead in the civilian remote sensing field in the world not only in terms of realization and launching of complex satellites with high, medium and coarse resolution cameras, but also in the application areas as well. In order to maintain this lead and also provide continuity of data to global users of GIS a dedicated satellite called Cartosat-1 with two improved fore and aft PAN cameras with better than 2.5 m spatial resolution is planned to be realized for launch by middle of 2003, and a series of Cartosat-2 satellites with better than 1 m spatial resolution and around 10 km swath in panchromatic band are planned to be launched by mid 2004 onwards. The Cartosat-2 series of satellites belong to small satellite class weighing about 600 kg and has the high agility capability to image any spot scenes along and across the ground track of the satellite. These satellites will provide the capability to update the large scale maps to the levels of 1:4000 to 1:2500 scales. With these satellites, several applications like mapping the individual settlements, morphometric analysis of urban features, declination of water sheds and individual fields are possible. This paper briefly presents the technical elements and the planned data products of the Cartosat-1 and Cartosat-2 series of spacecraft.

2. Cartosat-1 Spacecraft Technical Elements

The Cartosat-1 spacecraft is configured with the Panchromatic cameras which are mounted such that one camera is looking at +26 deg. w.r.t. nadir and the other at –5 deg. w.r.t. nadir along the track. These two cameras combinedly provide stereoscopic image pairs in the same pass. Also the whole spacecraft is steerable across track to provide wider coverage in a shorter period. A brief description of the payload and the other spacecraft elements are given below.

2.1 Cartosat-1 Payloads: The payload performs the function of imaging an area along the track and transmit the data for ground processing. Each panchromatic camera consists of three mirror off-axis all reflective telescope with primary, secondary and tertiary mirrors. These mirrors are made from special Zerodur glass blanks and are light weighted to about 60%. The mirrors are polished to an accuracy of $\lambda/80$ and are coated with enhanced $A10_2$ coating. The mirrors are mounted to the electro-optical module using iso-static mounts, so that the distortion on the light weighted mirrors are very minimum. The configuration of the electro-optical module of the camera is given in Fig.2.1.

In order to meet the high resolution and the swath requirement 12k, 7 micron linear array CCD is planned to be used as the detector. The CCD processing electronics will be using high speed devices to meet the high data rate requirements. Some of the important specifications of the payload are given in Table 2.1.

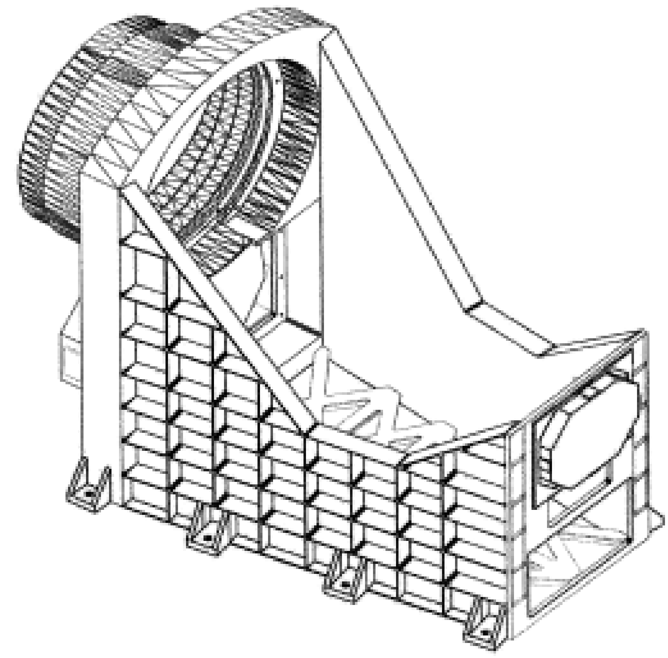

Fig 2.1 Electro-Optical Module Configuration of Pan Camera

2.2 Cartosat-1 Orbit Considerations: A polar sun synchronous orbit of altitude 618 km with an inclination of 97.87 deg. and an equatorial cross-over local time of 10:30 hours at the descending node has been selected based on various considerations. The sun-synchronous orbit provides the imagery collection under near-constant illumination conditions throughout the life and repetitive coverage of the same area in a specified interval. In order to revisit the same place at a more frequent interval than the repetitive cycle, an off-nadir viewing capability is provided. Using this facility any area which could not be imaged on a given day due to cloud cover, etc., may be imaged on another day. The typical revisit cycle is 5 days with the off-nadir cross-track steering facility. Important orbital specifications are given in Table 2.2.

2.3 Cartosat-1 Spacecraft Main Frame Systems: The spacecraft bus has to support the payload systems in terms of structure, thermal control, power supply, data compression, data formatting and encryption and transmissions, data storage, TTC etc. The spacecraft will be equipped with precision Attitude and Orbit Control System along with attitude sensors and propulsion systems. A brief description of various main frame systems is given below.

2.3.1 Cartosat-1 Platform Configuration: The spacecraft will be 3-axis body stabilized one by using 4 high torque Reaction Wheels mounted in a tetrahedral arrangement. The power generation capacity will be about 1100 watts at the end of life, to meet the global operation of the payloads. The overall spacecraft size will be about 2.4 x 2.7 m and will weigh about 1450 kg. The orbit configuration of the CARTOSAT-1 spacecraft is given in Fig.2.2.

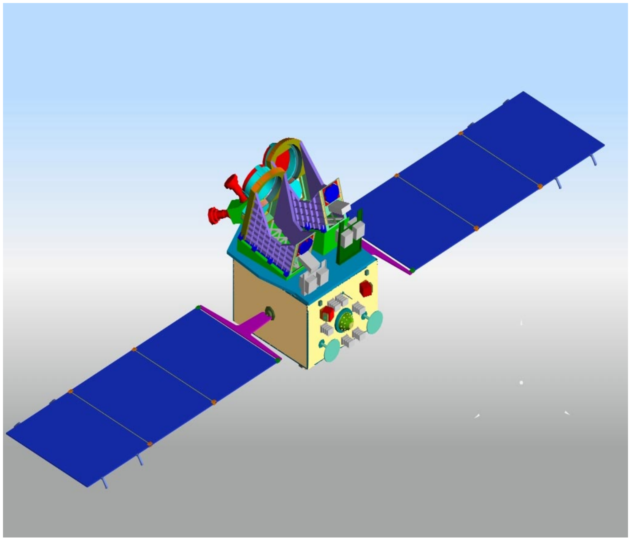

FIG 2.2 ON-ORBIT CONFIGURATION OF CARTOSAT-1 SPACECRAFT

2.3.2 Attitude and Orbit Control System (AOCS): In order to meet the stringent requirements of the high resolution payloads, it is necessary to have a precision Attitude Control System to provide a stable platform. Also in order to provide the required swath, overlap and to provide time invariant data and revisit requirements, the orbit control will be carried out periodically. Some of the important specifications of the AOCS are given below:

Attitude Pointing Accuracy (deg.) in all axes	: 0.05
Attitude drift (deg/sec.)	: 5×10^{-5}
Attitude determination accuracy (deg.)	: 0.01
Ground location accuracy (m)	: < 220

Table 2.1 : Payload Specifications

S.No.	Parameter Name	Specification Fore (+26 deg.) Aft (-5 deg)
1.	Spatial Resolution: GIFOV (m) (Across track x along-track)	2.5 x 2.78 2.22 x 2.23
2.	Spectral Resolution: a) No. of Bands : 1 b) Bandwidth Panchromatic : 500 nm to 850 nm	
3.	Radiometric Resolution: a) Saturation Radiance : 55 mW/cm*cm/str/micron b) Quantisation : 10 bits c) SNR : 345 at Saturation Radiance	
4.	Swath (km) (Stereo) : 26.8 Fore + Aft Combined (Mono)(km) : 55	
5.	CCD Parameters : a) No. of Detectors \ elements : 12000 per camera b) Detector Element size (microns) : 7 x 7 c) Odd – Even spacing : 35 microns staggered	
6.	Optics : a) No. of Mirrors : 3 b) Effective Focal length (mm) : 1980 c) F-Number : F/4.5 d) Field of view (degrees) : ± 1.08	
7.	Integration Time (ms)	0.366
8.	MTF : a) Across track b) Along track	 20 23
9.	Onboard Calibration	Relative, using LEDs
10.	Data Rate	105 Mb/s
11.	Data Compression a) Algorithm, b) Compression Ratio	JPEG Max. 3.2
12.	Nominal B/H Ratio for Stereo	0.62
14.	P/L Operating Temp. Range	20 +/-1 deg.C

Table 2.2 Orbit Specifications

S.No	Orbit Characteristic	Specification
1.	Nominal Altitude (km)	617.99
2.	Number of orbits per day	15
3.	Orbital Repetivity Cycle (No. of days)	116
4.	Nominal Wait Time to Acquire Adj. Path	11 days.
5.	Max. wait time for revisit	5 days
6.	Node for P/L operations	Descending Node
7.	Local Time for Equatorial Crossing	10:30 A.M.
8.	Orbital parameters : a) Semi-major axis b) Eccentricity c) Inclination	6996.128 km 0. 002 97.87 deg.

The drift rate determines the image internal distortion figures, whereas the jitter affects the resolution parameters. The AOCS will meet the stringent attitude pointing accuracy and the stability using a wide area star sensor in Attitude Control loop and better control algorithms and using dynamic friction compensation technique for the ball bearing Reaction Wheels. AOCS will be configured with MIL-STD 31750 processor and with ASIC and HMCs. Various sensors like, earth sensors, star sensors, precision yaw sensors and precision digital sun-sensors will be used to control and determine the attitude of the spacecraft precisely. Hydrazine mono-propellant Reaction Control System with 4 nos. of 11 Newton thrusters and 8 nos. of 1 Newton thrusters will be used for backup control and for momentum dumping purposes. About 131 kg of RCS fuel will be planned to provide a minimum mission life of 5 years.

2.3.3 Earth Rotation Compensation: In the case of along track stereo data acquisition, same scene on the surface of earth is imaged with a time difference. The time difference is a function of the difference in forward and backward look angles chosen from other criteria and can be anywhere between 50 and 100 seconds. Major change in imaging conditions during this time period is due to rotation of earth. At the equator the effect of earth rotation is to shift the imaged point to the East by a distance of approximately 463.3 m for every one second. Thus during 50 seconds the shift is of the order of 23.2 km. At 25 degrees latitude, the shift is 20.09 km. If the separation in time between forward and backward imaging is more than 65 seconds then no overlap between them is present in case of zero yaw angle. In order to ensure stereo imaging it is necessary that the aft camera views the earth's surface in such a way as to image the shifted point. This condition can be achieved by a continuous yaw manoeuvering. For any given latitude, it can also be achieved by mounting the payloads at appropriate yaw angle with respect to each other. A combination of fixed mounting, catering to stereo acquisition requirements for Indian latitudes and a yaw manoeuvring for other regions with minimum power consumption shall be adopted. Alternatively the spacecraft is manoeuvred such that the image strips will fall side by side so that wider swath images are obtained by the two cameras.

2.3.4 Data Handling System: The realization of high precision cameras calls for the development of very high speed precision electronic systems, and requires gain bandwidth of low noise analog system in the range of a few GHz. Due to small IFOV, the signal amplitudes are also expected to be very low. The detectors also require ultra low noise, biases and high frequency read out clocks. The data rate requirement for 2.5 m. resolution system is about 340 MBPS for a typical 10 bit quantisation. This high bit rate Data is compressed by 3.2:1 by JPEG Compression technique to bring down the data rate to 105 m compatible for X-Band Data transmission system. The payload data is transmitted in two X-band carriers one for each PAN camera, after QPSK modulation to the Data Reception Station (DRS). A spherical Phased Array Antenna with steerable beam to the required DRS is used to transmit the payload data. A solid state recorder with 120 GB capacity to store about 9.5 minutes of payload data and playback to the required ground station is also planned for the global operation of the payloads.

3. Cartosat-2 Spacecraft Elements

The spacecraft is configured around a single pancrhomatic camera and the whole spacecraft is steerable across and along track to image any spot scenes along the ground track. A brief description of the payload, orbit and the other spacecraft elements are given below.

3.1 Cartosat-2 Payload: Considering the Cartographic application as the prime requirement a single Panchromatic Camera is chosen for Cartosat-2 series of satellites. Based on the required resolution and swath and to accommodate the camera within the size and weight of the spacecraft, the optical system is designed with two mirror Ritchen-Chretion (RC type) on-axis obscured reflective telescope system with a concave hyperboloidal primary mirror and convex hyberboloid secondary mirrors and the field correcting relay optics. The mirrors are made of special Zerodur glass and are light weighted to about 60% as in Cartosat-1 series. These mirrors are mounted inside the telescope cylinder made of CFRP with special mirror fixation devices called MFDs and the whole telescope assembly is mounted to the spacecraft structure through special suspension arrangement. The detector and detector electronics are identical to Cartosat-1 payload. The optical system is designed to provide 1 meter resolution across track. The along track GSD of 1 meter is achieved by apparent velocity reduction by a factor of 2.5. The spacecraft can be suitably biased to provide various modes of imaging : 1) continuous strip mono mode, 2) spot scene imaging and 3) paint brush mode of imaging.

3.2 Cartosat-2 Orbit Selection: Based on the payload design and spacecraft bus, a near circular sun-synchronous orbit of altitude 630 km. with an inclination of 97.914 deg. has been chosen. Some of the orbital parameters of Cartosat-2 are given below.

Table – 3.2 Orbital Paremeters of Cartorat-2

Nominal altitude (km)	:	630
No.of orbits per day	:	14
Revisit with $\pm$ 26 deg.roll tilt capability.	:	4 days
Equatorial crossover time	:	09.30 h

3.3 Cartosat-2 Spacecraft Elements:

The Cartosat-2 spacecraft will be a small satellite bus with the spacecraft mainframe elements built around the camera telescope. The spacecraft will be of three axis stabilized configuration with fixed solar panels such that the panels along with the spacecraft will be pointing towards the sun during non-imaging durations and during imaging the spacecraft yaw axis which is the optical axis of the spacecraft is made to point towards the imaging regions. The spacecraft solar panels have the power generation capacity is about 800W because of the usage of high efficient multi junction solar cells. The on-orbit configuration of theCartosat-2 spacecraft is given in Fig. 3.1.

Fig 3.1 ON-ORBIT CONFIGURATION OF CARTOSAT-2

3.4 Attitude and Orbit Control System: In order to meet the high agility and high pointing accuracy and to provide step and stare capability, and high stability and to meet the various imaging modes of the spacecraft platform, high precision star sensors, high torque reaction wheels and making use of complex control algorithms, have been planned to be realized. AOCS system also orient the double gymballed data transmission antenna to point towards the required Data Reception Station during the orbital motion of the spacecraft. The initial acquisition and 3 axis stabilization is carried out using mono-propellant hydrazine thrusters. About 69 kg of fuel is planned to provide a minimum mission life of 5 years.

3.5 Data Handling and Transmission System: The Data Handling System is identical to the Cartosat-1 except the data transmission is through dual gimbal antenna and the antenna beam is made to point towards the required ground station during imaging.

4. Cartographic Data Products

The overview of the Cartosat Data Products generation facility is given in Fig.4.1. The main constituents of this facility are, 1) Data Archival and Quick-look Browser (DAQLB) Systems, 2) Data Processing System (DPS) and 3) Cartosat Data Centre (CDC). The CDC interfaces with the Cartosat user community in getting the user requirements and processing the archived or acquired data, making use of the sub-modules like Stereo Strip Triangulation (SST), the Ground Control Points Library (GCPL) and the Data Products and Services modules. The stereo strip triangulation subsystem takes the primary GCPs and the DLT as input and generates (1) Triangulated Control Points (TCP), (2) Coarse DEM and 3) Updated orientation parameters. The TCPs and coarse DEMs and the IMS work order are the inputs for data products generation subsystem along with DLTs for generation of Data Products operationally. Various types of Data products planned using Cartosat images are (1) Image Data Products, (2) Image Map Data Products and (3) DEM Data products.

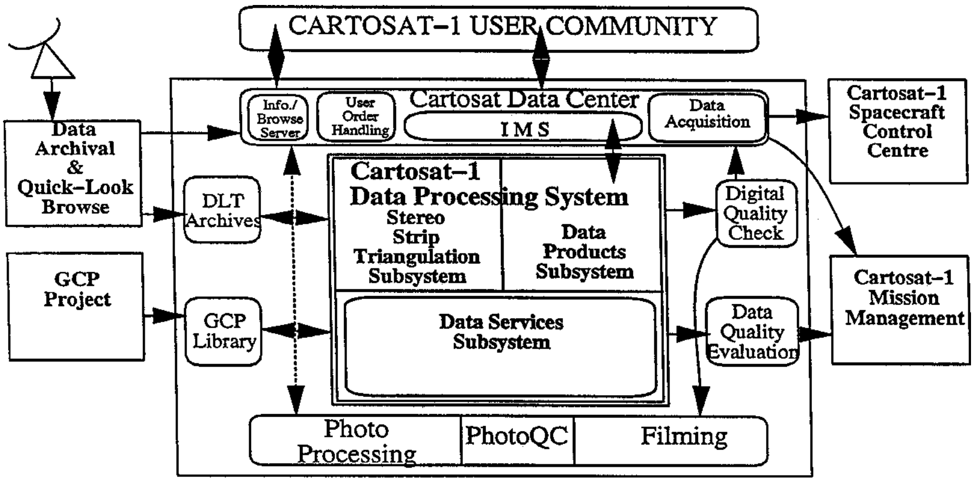

Figure 4.1 Cartosat-1 Data Products Generation Facility

5. Conclusion

Several countries, apart from India have embarked on space based remote sensing. A number of remote sensing satellites launched in the last decade such as Landsat, SPOT, ERS and IRS series have shown very encouraging results for variety of land, coastal and marine applications. They also have aggressive plans for advancing the remote sensing technologies for different applications in future. In India ISRO has taken a lead in

Land Resource application Satellites and has evolved plans to sustain and advance in all areas of earth resource applications. Basically, Indian Space Programme in the Remote Sensing area plans for improved missions in the areas of a) Cartographic Applications (b) Land and Agricultural applications, (3) Oceanographic applications, (4) Atmospheric Applications and (5) Climatic applications. Although globally there have been many satellite systems being operational and planned with higher resolutions to meet the ultimate information requirements of the user community for geo-engineering applications and cadastral requirements, the launch of Cartosat series of satellites is expected to meet the immediate demands, for terrain visualization, updation of topographic maps, generation of National topographic data base, utilities planning and other GIS applications.

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