Acquisition, Processing and Image Generation System for Camera Data Onboard Spacecraft

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Abstract
The primary goal of any communication spacecraft is to provide communication in variety of frequency bands based on mission requirements within the Indian mainland. Some of the spacecrafts operating in S-band utilizes a 6m or larger aperture Unfurlable Antenna (UFA for S-band links and provides coverage through five or more S-band spot beams over Indian mainland area. The Unfurlable antenna is larger than the satellite and so the antenna is stowed during launch. Upon reaching the orbit, the antenna is deployed using motors. The deployment status of any deployment mechanism will be monitored and verified by the telemetered values of micro-switch position before the start of deployment, during the deployment and after the completion of the total mechanism. In addition to these micro switches, a camera onboard will be used for capturing still images during primary and secondary deployments of UFA. The proposed checkout system is realized for validating the performance of the onboard camera as part of Integrated Spacecraft Testing (IST) conducted during payload checkout operations. It is designed for acquiring the payload data of onboard camera in real-time, followed by archiving, processing and generation of images in near real-time. This paper presents the architecture, design and implementation features of the acquisition, processing and Image generation system for Camera onboard spacecraft. Subsequently this system can be deployed in missions wherever similar requirement is envisaged.
Keywords:
Unfurlable Antenna, Camera data, LVDS, RDBMS, CCSDS, SQL, Client-Server, RAID, CRC, FPGA, APS

1. Introduction

The camera, shown in Figure 1, is essentially a CMOS based monochrome camera and is similar to the camera planned for one of the inter planetary missions. It is a compact camera which can operate in harsh environmental conditions like space and is based on a STAR 1000 Radiation hardened APS (Active Pixel Sensor) detector and an Actel Radiation hardened FPGA to drive the detector. This camera in one of the inter planetary missions was designed for baseband data handling interface and Solid State Recorder storage. However, in the absence of baseband handling system in one of the satellite missions, the camera head is developed to have an interface electronics unit which has in-built memory and interface option for telemetry. The camera consists of radiation hardened STAR1000 CMOS detector with 1k x 1k (1024 x 1024) pixel. The camera data will be stored in the on-board memory and will be transmitted to ground at 3Mbps data rate. The specifications of the camera are given in Table-1. The typical camera storage time versus frame rate is given in Table-2. The camera download time versus download data rate is given in Table-3.

The paper is organized into eleven sections. Section 1 provides introduction. Section 2 briefly describes the telemetry data or camera data. Section 3 presents details of transmitter operating in C-band. Section 4 gives what is randomization and the randomization scheme adapted onboard. Section 5 provides the details of ground data reception system. Section 6 gives the details of the checkout software system used and the salient features of the software system. Section 7 details the software tools used in designing and realizing the checkout software system. Sections 8 gives the minimum hardware and minimum software configurations of the computer system used respectively for testing the implementation. Section 9 provided the results and discussion. Section 10 gives the future scope and Section 11 summarizes the work carried out.

Figure 1. Typical Onboard Camera

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Parameter	Specifications
Type	Monochrome
Pixels	1024x1024
Data Rate	3 Mbps
Frame Rate	3 fps
Frame Size	1053696 Bytes
Storage	1 GB

Table 1 Typical Camera Specifications

Frame Rate	Frame Time	Memory Size	Storage Time
3 fps	0.333 sec	1GB	5 Minutes
1 fps	1 sec	1GB	16 Minutes
50 fpm	1.2 sec	1GB	20 Minutes
30 fpm	2 sec	1GB	33 Minutes
20 fpm	3 sec	1GB	50 minutes
10 fpm	6 sec	1GB	100 Minutes
8 fpm	7.5 sec	1GB	120 Minutes
5 fpm	5 sec	1GB	200 Minutes

Table 2 Typical Camera storage time vs frame rate

Download Rate	Full memory (1 GB) Download Time
9 Mbps	15 Minutes
6 Mbps	23 Minutes
3 Mbps	45 Minutes
1 Mbps	133 Minutes
0.5 Mbps	264 Minutes
0.1 Mbps	1320 Minutes

Table 3 Typical Camera D/L time vs D/L data rate

2. Data Telemetry (Camera Data)

Camera will send the image data serially from interface card using LVDS interface. The data will be transmitted to Transmitter at 3 Mbps data rate. The data frame consists of 1028 Kbytes of data. The data frame starts with 512 bytes of Header bits containing frame counter information. Every 512 bytes of data, 16 bits CRC (Cyclic Redundancy Check) code is also transmitted. Every image frame starts with 512 bytes of header bits. It is required to process all header parameters over the lines of frames acquired to check for their validity and integrity.

3. C-Band Transmitter

The captured image data will be stored in the form of frames in the on-board memory storage (typically of the order of Giga Bytes) of the camera electronics. This is required to be transmitted to ground at high speed via Radio frequency (RF) link. The data will be collected by ground using data reception system, processed on ground and displayed in the form of a video.

A dedicated C-band transmitter is planned for transmitting the data to ground via downlink. The transmitter will provide BPSK (Binary Phase-Shift Keying) modulation at 3 Mbps data rate at C-band downlink frequency. It will require 45 minutes, as given in Table 3, to download the entire 1GB data through the proposed RF downlink.

4. Randomization

Randomization of data is done to spread the spectrum and also to introduce bit transitions in the formatted stream in the absence of payload data.

Onboard Randomization is done as per the standard randomization scheme. Randomization will start after Asynchronous Sync Marker (ASM) bytes. Derandomization on ground has to be done using the same polynomial that was used in onboard. Derandomization can be done at hardware level or at software level. The data reception system has both these capabilities of derandomization at hardware level and derandomization at software level.

5. Ground Data Reception System

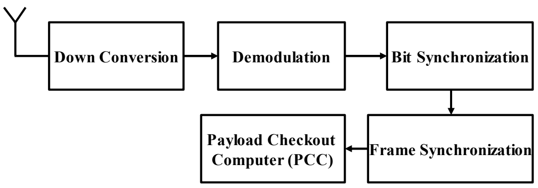

Figure 2. Schematic of Typical Ground Data Reception System

Schematic of Ground Data Reception System realized is shown in the Figure 2. Details of the software system and configuration of the PCC are depicted in section 6 and in section 8 respectively.

All earth observation missions realized by Space Organization in India has framelengths of order of thousands of bytes and data rates starting from few Kbps upwards to few Gbps.

All missions use different modulations schemes namely BPSK, QPSK, 8PSK with varying channel codings based on the mission requirements and applications.

When compared with those missions, the handling the data rate of few Mbps and large framelength of order of mega-bytes in the spacecraft under consideration is unique and quite challenging.

Spacecraft Checkout Group at U.R.Rao Satellite Centre has various kinds of data reception systems with some systems developed in-house and some other systems being procured based on requirements envisaged for various spacecraft missions currently going on and missions planned for future.

These requirements, among other things include, handling varying data rates, handling varying modulation schemes as mentioned above, different channel coding schemes adapted, variety of compression/encryption methods employed onboard and varying framelengths and data formats used. Data formats include, among others, Consultative Committee for Space Data Systems (CCSDS) data format & conventional data formats used in many of indigenous missions. Combinations CCSDS data and conventional data format are also used in some of the missions.

After in-depth study of the formatting details of the onboard Camera, it was found that none of the data reception systems that are available can cater to all the mission specific requirement of spacecraft onboard Camera.

One of the data reception system available is upgraded to handle the specifications of spacecraft under consideration.

Updated data reception System has the capability of required demodulation (BPSK), bit-synchronization, frame synchronization and derandomization. It can handle the required data rate of few Mbps and make the payload data available to the client systems over TCP/IP via Ethernet

The typical baseband configuration used in the data reception system for IST is depicted in Figure 3

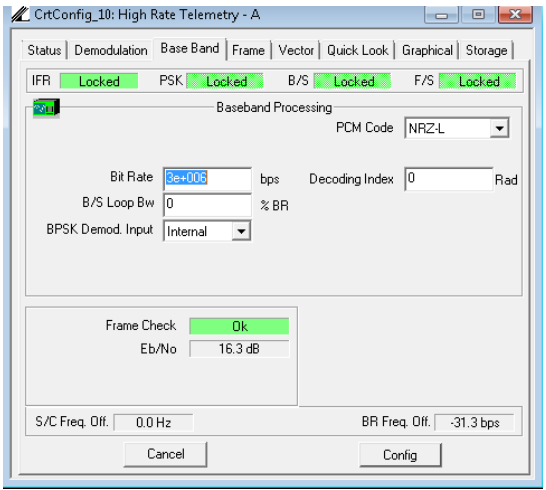

Figure 3. Typical Baseband Configuration

The Received RF signal undergoes down conversion to generate the 70 MHz IF frequency, compatible for the demodulator by index. The BPSK demodulator will retrieve data and clock is recovered with help of bit synchronizer. Data Reception System is used for BPSK demodulation, bit synchronization, de-randomization and frame synchronization.

The data reception system acquires serially camera telemetry data in real time and makes the data available over TCP/IP to client system.

Payload Checkout Computer (PCC) acquires the demodulated, derandomized camera data from data reception system over TCP/IP in real-time and archives in real time the camera data on to the hard disk drive and makes the data available for further processing and for subsequently image generation.

For higher data rates, the available Hard Disk Drives (HDDs) are logically combined to a single logical RAID (Redundant Array of Inexpensive Disks) volume configured in RAID-0. This will improve the throughput for writing the collected data onto RAID volume and reading from the RAID volume.

6. Software system for camera data collection, validation and image generation

Software system is designed as generalized, modular, mission critical software system and is called as Checkout Software for Remote Sensing Payloads (CSRSP). This software system is referred from now onwards as CSRSP. This software system has the designed features among other things for:

- Real time acquisition using various data reception systems (low bit-rate, medium bit-rate and high bit-rate)
- Archival of the acquired data in the way it is received from data reception system
- Pre-processing schemes (channel decoding schemes, decryptions schemes, decompression schemes, alignment and formatting the packed data into 8 bit words or into 16 bit words based on pixel depth)
- Archival of pre-Processed data
- Processing of auxiliary data
- Processing of payload (camera) data and archival of the same
- Image generation
- Real time data can be collected in terms of number of lines, time duration or volume of data.

And other features being analysis of high bit-rate data from payloads and associated subsystems like baseband data handling, solid state recording systems, data compression systems onboard remote sensing, scientific and interplanetary missions.

The software system is designed using 3-tier client server architecture, developed under Linux Environment. The 3-tier client server architecture makes a logical separation between the presentation layer, logic layer and database layer. All the three layers can be deployed on the same computer system or on two different computer systems (where two layers on one system and other layer on other system) or on three different computer systems (all three layers on three different computer systems).

The motivation behind going for three tier architecture is:

- It is easier to update, or modify or replace any of the three tiers without affecting the other two tiers.
- Separating the database functionality and application functionality means better load sharing.
- It is easier to enforce adequate security policies within the server tiers without hindering the clients.

This software system has the capabilities for derandomization at software level and for performing the CRC at software level on the received data.

The hardware configuration used is given in Table 4. Software configuration is depicted in Table 5. The architecture of the software system is shown in the Figure 4. This software system runs on Payload Checkout Computer (PCC) with minimum configuration is depicted in section 8.

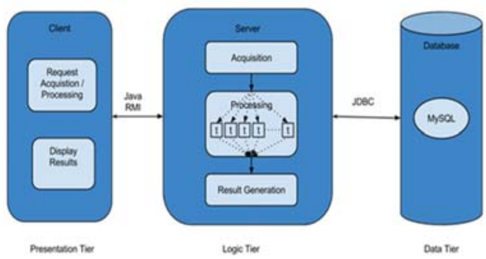

Figure 4. Architecture of Software System

7. Software Tools Used

State of the art technologies that are used for realization of the software system, CSRSP are:

- MySQL is used for database management and forms the bottom layer or also known as database layer.

Parameter	Specifications
Make	HP
Model	Proliant DL 585-G7
RAM	4 GB
HDD (RAID)	300 GB
Processor	AMD Opteron 6136 2.4 Ghz
NIC	1 GB

Table 4 Configuration of PCC

Description	Configuration
Operating System	Redhat Enterprise Linux 7.5
RAD Tools	VS Code and Golang
Database Server	MySQL Server 5

Table 5 Software Configuration

- All configurable parameters such as frame length, number of pixels, pixel depth, frame sync are managed in this tier. Any of the relational database management systems like MS SQL Server can be used. Hence MySQL is chosen to implement this layer
- Java and Remote Method Invocation (RMI) are employed for development of server and middle layer.
- Java used for design of application layer/top layer which is also known synonymously as presentation layer.
- Java Imaging Library is used of generation of Images.
- Databases are designed to confirm to 4th normal form 4NF
- Has the capability for various channel decoding schemes and source de-coding schemes.

The architecture of the software system is depicted in Figure 4.

8. Configuration of the PCC

Payload Checkout Computer (PCC) system is configured and used for collecting the camera data from Data Acquisition System in real time followed by processing and validation, image generation and archival of the data.

Minimum Hardware Configuration required for the Payload Checkout Computer (PCC) system shown in the Table 4. The higher the hardware and software configuration of the PCC, the better will be the performance of the system.

9. Results & Discussion

Figure-5 shows one of the Images generated by the software system during integrated spacecraft testing of satellite. The system is extensively used during the spacecraft level tests before launch and also deployed for post launch operations of satellite with 6m UFA.

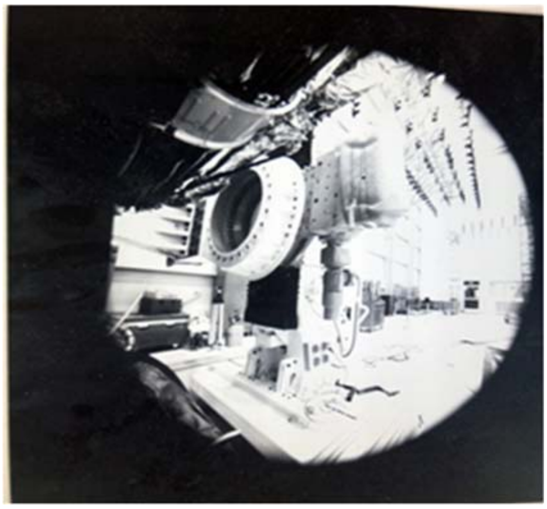

Figure 5. One of the Images Generated

The additional parameters or markers other than the camera/ payload data added in the data format are called as auxiliary data. As part of testing, these auxiliary data are also validated for all the acquired data and sample report of auxiliary data is depicted in Table-6.

These auxiliary parameters indicate the quality of the data received or acquired. The auxiliary consolidated report generated for all auxiliary parameters is shown in Table-6.

The image generated after launch will indicate visually whether the UFA antenna is deployed completely or partially deployed or not deployed at all.

Parameter	Status
ASM	OK
FrameLength	OK
Spacecraft-ID	OK
FrameCounter	OK
FrameTime	OK
Integration Time	OK
SensorGain	OK

Table 6. Sample Auxiliary Consolidated Data Report of Camera Data

This system can be deployed for any Geo, Leo, Interplanetary or Scientific mission carrying similar camera systems and the camera data is used for verification of the deployment status or any other purpose specific to the mission objectives.

The system can be used for payload data acquisition and image generation of Nano Satellites with miniature multispectral imaging payload.

Subsequently the image generation software is used during integrated satellite tests of series of radar imaging satellites for verification of status of motorized deployment mechanisms of onboard Radial Rib Antenna (RRA). RRA is a 3.6m antenna system which was folded and stowed during launch and later deployed in obit.

The same system can be deployed for monitoring the deployment of 12 m Unfurlable antenna onboard radar imaging satellite, a joint venture of Indian Space Organization and American Space Agency.

10. Future Scope

The system is extensively used during Integrated Spacecraft Level Testing during all phases of many earth observation spacecraft missions.

This system can be deployed for any Geostationary, Low earth or Interplanetary missions carrying similar camera systems and can be used for verifications of the primary and secondary deployment mechanisms during spacecraft integrations level testing (IST) and subsequently during in orbit testing (IOT).

This system can also be deployed for the characterization of optical payloads onboard various types of satellite missions.

11. Conclusion

The system is realized, undergone required rigorous review processes, thoroughly validated before deployed for the payload checkout activities of the identified satellite mission. Camera data is acquired in real-time, archived, processed and image generated in real-time during IST. And the IST is carried out in both RF cable mode and radiated modes. The test data is given to the subsystem team and results are presented to the relevant project review committees.

This system can be deployed for any Geostationary, Low earth or Interplanetary missions carrying similar camera systems. The system can be used for capturing the images of payloads getting separated form launch vehicles.

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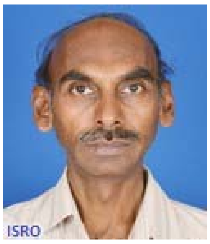

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