Preliminary Design Architecture of Onboard Data Handling System for RVSAT-1

Aravind D Kenchakanavar[1], Praveena B[2], Sravanti K Ramesh[3], G V Keerthi[4]
[1,2,3,4]*Department of Electronics & Communication Engineering*
R.V. College of Engineering, Bengaluru, India
arvindkenchakanavar.ec15@rvce.edu.in, praveenab.ec17@rvce.edu.in, sravantikramesh.ei16@rvce.edu.in, gvkeerthi.ec17@rvce.edu.in

Abstract: Nano-satellites are compact miniature versions of conventional engineered satellites. RVSAT-1 is a 2U Nano-satellite of CubeSat standards, aimed at analyzing growth and behavior of microbial organisms in zero gravity conditions as payload. On-Board Data Handling(OBDH) system is the brain of the Nano-satellite which monitors and controls all functions of the satellite autonomously throughout the mission life of the satellite. The mission of the satellite determines the hardware and software architecture. This paper focuses on the preliminary design of single processor based OBDH system of RVSAT-1 and covers the interfacing of other subsystems with Onboard Computer (OBC). The functions monitored and controlled by OBDH system are explored in the subsequent sections.

Keywords: Nano-satellite, Onboard Data Handling, Onboard Computer architecture.

I. INTRODUCTION

Concept of Nano-satellites extends the research in different fields of science using space technology being more advantageous in cost-effective methods to design and manufacture of satellite and thus even an individual can have access to space. There are different subsystems which contribute towards systematic functioning of a satellite, which are Attitude Determination and Control(ADCS), Electrical Power system(EPS), Telemetry Tracking and Command(TT&C), Thermal control, Structures and Onboard Data Handling(OBDH). The major functionalities of OBDH are classified as collecting, processing and formatting of satellite health data and payload data for downlink and as receiving, decoding and distribution of command to other systems of the satellite sent from the ground station. For design of OBDH system hardware architecture, a microprocessor with low power consumption, high processing capacity and low cost is required considering the constraints on the size of Nano-satellite and power storage capacity. the main necessities of an on-board computer are high reliability, efficiency, mass, real time processing, minimum energy consumption and resistance to radiation. The software of OBDH includes efficient algorithms for different functions of the system to ensure autonomous operation of satellite during different modes of the satellite throughout mission period. The operation of the onboard computer(OBC) starts when the satellite is deployed from launch vehicle and controls the satellite till end of mission period. It executes the predefined software to communicate and control sensors and actuators and ensures sequence of data flow of the operation of the satellite. Health data and payload data is stored in flash memory and health data is transmitted as telemetry data through beacon and payload data is downlinked to ground station. OBC monitors and controls attitude and orientation of the satellite and also can efficiently manage power distribution in the satellite.

Section 2 provides an overview of architecture of the OBDH system and discusses about the features of microcontroller chosen for design of OBDH system and section 3 explains interfacing of sensors and actuators of other subsystems with OBC and also elaborates about the functions of sensors and actuators controlled by OBDH and followed by conclusion.

II. OBDH SYSTEM DESIGN

The OBDH system design is based on centralized architecture where the satellite is governed by a main processor and all peripherals are connected to main processor. The hardware components of OBDH system are onboard computer, Flash memory and the data interfaces to the different subsystems. Upcoming section explains the interfaces and data flow, and functionalities of each hardware component.

Considering performance of microcontroller, a high-performance controller STM32F407VGTx was selected as microcontroller for OBDH system. STM32F407VGTx is an ARM Cortex-M4 based 32-bit RISC architecture controller with features of floating point unit and memory protection unit, contains GPIO pins and communication interfaces like I2C, SPI and UART. The microcontroller also has I/O pins for digital-to-analog(DAC) and analog-to-digital(ADC) conversion, CRC calculation unit and Real time clock (RTC). The controller operates at 1.8V to 3.6V power supply and consuming 145mW of power. The controller offers flexibility of operation by switching between sleep, stop and standby modes for effective power usage. The controller programmed using JTAG *interface. Keil* IDE is used for programming and Debugging.

III. OBDH SYSTEM INTERFACES

This section describes the interfaces and functionalities of each sensor and actuator of other subsystem with OBC.

A. Attitude Determination and Control

The goal of ADCS is to stabilize, attitude determination and control, along with position determination of the satellite.

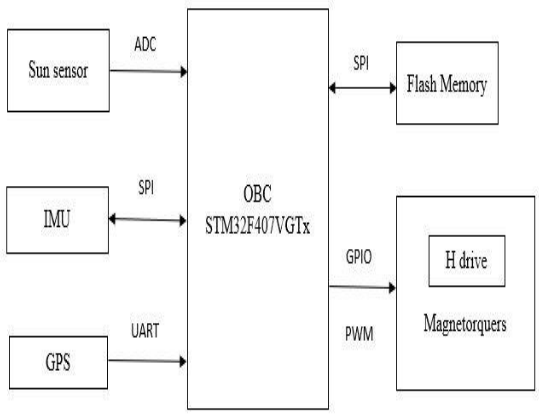

Figure 1. Interface of OBC with ADCS and Flash memory.

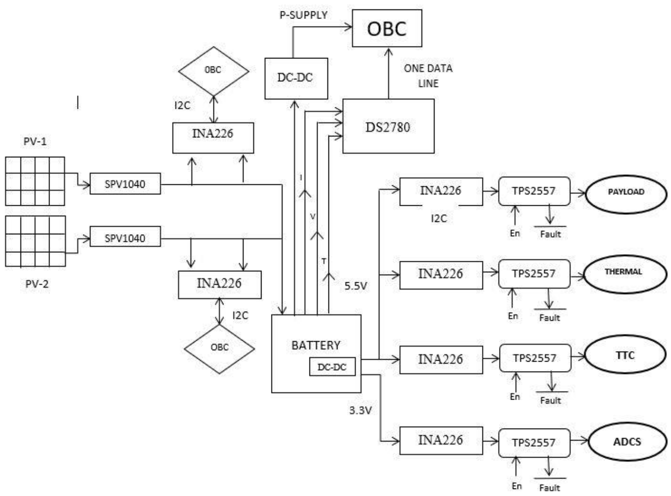

Figure 2. OBC interface with Electric power system.

These goals are achieved using different sensors and actuators. Figure 1 shows the interface between ADCS components with OBC. The functionalities of which are controlled and monitored by OBC as follows,

1) Sun sensor

It determines the orientation of the satellite with respect to the Sun. It consists of a CMOS PSD detector. Based on the angle of incidence of Sunlight, output of the sensor depends on the intensity and wavelength of the light incident and generates the analog output voltage. It is calibrated such that it measures the Sun vector from these voltages using computational algorithms. NSS CubeSat sun sensor are used in RVSAT-1. All 6 sensors are interfaced to microcontroller by Analog-to-Digital(ADC) pins and STM32F407VGTx has 12-bit ADC with usage of 5 channels out of 16 external channels.

2) Inertial measurement unit(IMU)

IMU includes a magnetometer, gyroscope and accelerometer. Three axis magnetometer measures the direction and strength of the magnetic field acting on satellite body and is used in attitude determination and control. Gyroscopes measure the rate of spinning about an axis and the accelerometer detects a force which is directed in the direction opposite from the acceleration vector. The IMU used here is ADIS16480 and mainly consists of triaxial accelerometer, triaxial gyroscope and triaxial magnetometer and communicates via SPI interface to microcontroller for data collection and configuration control.

3) Magnetorquer

Magnetorquers are the actuators used to point the satellite at the required orientation. Magnetorquers are magnetic coils which induce magnetic field on passing current through the coils which interact with earth's magnetic field and produce torque to orient the satellite. 3-axis Magnetorquer is used to stabilize satellite in 3 dimensions. Control algorithms are executed to actuate the magnetorquers in detumbling mode,3-axis stabilization mode of the satellite. Pulse width modulation(PWM) is the method used to actuate the torquers by passing current through magnetic coils to achieve required orientation and stabilization. Timer functionality of microcontroller is used in PWM algorithm. Magnetorquers SatBus MTQ, designed by NanoAvionics are used in RVSAT-1 which is interfaced to GPIO pins of OBC.

1) GPS

GPS is used to get initial two-line elements of the satellite which will be used by ADCS as well as TT&C for position and time for field of view prediction. The GPS receives NMEA data from the satellites and from this information on latitude, longitude and altitude extracted. These data help to determine the Two-line element set. Here piNVA-NG GPS is used, communicates to microcontroller through UART interface.

B. Electric power system

One of the most critical component of the satellite is Electrical Power System. It consists of solar panels, battery system, central power conditioning and management system. The main function of EPS is to generate, store and distribute spacecraft electric power. It is designed to provide stable power to all the subsystems. The figure 2 illustrates the interfacing of OBC along with Sensors of EPS systems of RVSAT-1. OBC monitors SPV1040 consisting of MPPT and BCR gives the peak power produced from the solar panels and charges the battery at optimum voltage and current. The power harnessed is sensed by INA226 current and voltage sensors which measures maximum current and voltage values and sends the data to OBC through I2C interfacing. These values are analyzed for health monitoring in OBC to check if they are within the required operating range. After the evaluation it is sent to charge battery which supplies stable power to different components of the satellite. From the battery, 5V is supplied to the OBC through LTC3440, a Buck Boost DC/DC converter that provides a constant voltage. 3 more lines from the battery are connected to DS2780 fuel gauge IC to measure the current, voltage and temperature values and to estimate the capacity of the battery. It sends the measured values to OBC using USART communication. The current, voltage and temperature readings are stored as telemetry data. Voltage bus of 5V and 3V are used to supply the required power to each subsystem. Each bus line voltage and current values are measured by INA226 and stored as health data. TPS2557 is a current limiting switch which breaks the load line during over current and it is again enabled by OBC through enable signal.

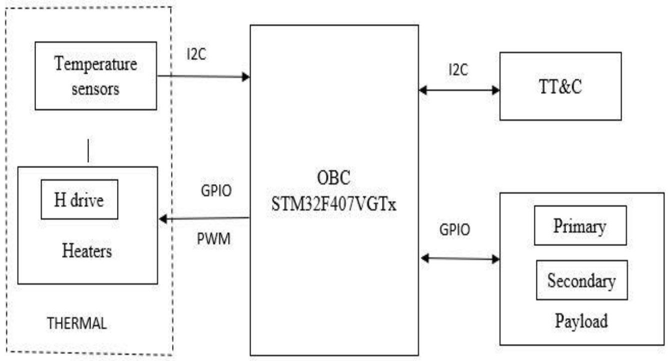

Figure 3. Interface of Thermal system, TT&C and Payload with OBC

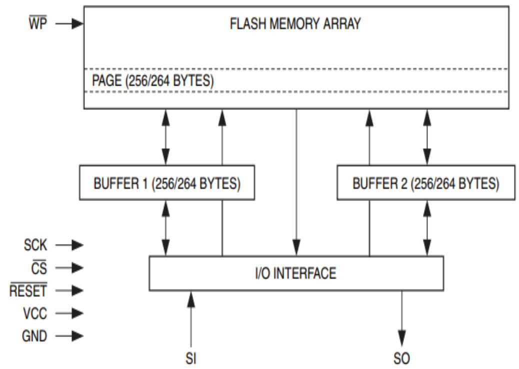

Figure 4. Flash Memory Architecture

C. Thermal control

Thermal system's function is to maintain the satellite in safe operational temperature range. It contains temperature sensors and heaters. Based on the thermal analysis, heater will be placed in appropriate position of the satellite. By monitoring temperature sensors, heater is controlled to maintain safe operating temperature range. Figure 3 illustrates interface of Thermal system with OBC. Temperature sensors are connected to I2C bus and heaters are actuated using PWM method and connected to microcontroller through GPIO pins.

D. Telemetry, Tracking and Command

OBC collects data from various subsystems of the satellite as health data for telemetry and stores in flash memory and transmits to TTC at regular intervals through I2C bus of OBDH. Health data consists of system time, voltage, current and temperature of subsystems; the health data is formatted before transmitting and payload data is transmitted during downlink to ground station. Telecommand is the uplinked command data which OBC decodes and distributes the commands to intended subsystems as per the command code. Figure 3 illustrates interface of TT&C with OBC.

E. Flash memory

An external memory is required to store two types of data, which are health data and payload data. Health data is logged periodically into flash memory and processed as beacon signal, which is used to analyze the operation status of the satellite. Payload data is collected after each experiment and sent to ground station when the satellite is in field of view.

Flash memory Atmel AT45DB081 is used in RVSAT-1. This is a serial interface Flash memory ideally suited for a wide variety of digital voice, image program code and data storage applications. Its data retention is up to 20 years. Figure 4 shows architecture of Flash Memory. Serial interface is SPI with OBC and can operate up to frequencies of 66 MHz and memory size is 8MB.

F. Payload Interface

The payload of RVSAT-1 is divided into primary and secondary, Primary being deorbiting of the satellite using electrodynamic tether and secondary an Astro- biological payload. The secondary payload is a biological experiment carried out in the satellite. The components of the experimental setup particularly light source and the detector are actuated at the time of the experiment by onboard computer. The output of the detector is analog voltage which is processed and stored in flash memory and downlinked to ground station during field of view through TT&C. The tether deployment system is actuated at the end of mission of the satellite by OBC which ensures controlled deployment of tether from satellite and thus aids in effective deorbiting. Figure 3 illustrates interface of Payload with OBC.

IV. CONCLUSION

In this paper the architecture design of OBDH is discussed. The design of OBDH focuses on use of high performance microcontroller and interfacing of each component of other subsystem based on selection of hardware is defined. Also, a discussion about functionalities monitored and controlled by OBDH system with each sensor and actuator is presented. The implementation of the proposed architecture represents potential area of study and also validates the architecture design.

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