Design and Implementation of an Onboard Computer and payload for Nano Satellite (CubeSat)

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Abstract*– The satellite has many subsystems that require an onboard computer to organize and handle the data of satellite subsystems to send it to the ground station. The On-Board Computer (OBC) is the brain of the satellite. We designed and implemented an onboard computer for a CubeSat type of nanosatellites. The project can be divided into two virtual parts, satellite, and ground station. We used an ATmega328 microcontroller which acts as the onboard computer and sensors such as IMU, temperature, radar, BMS, and ESP32 CAM to act as satellite subsystems. The all-software code is run over a real-time operating system called FreeRTOS. FreeRTOS provides methods for multiple threads or tasks, mutexes, semaphores, and software timers. FreeRTOS, therefore, provides the core real-time scheduling functionality, inter-task communication, timing, and synchronization primitives only. This means it is more accurately described as a real-time kernel or real-time executive. We manufactured a 3D-printed CubeSat to house our onboard computer unit and fabricated a 3-layer PCB to shield our components.

Keywords—OBC; CubeSat; Nanosatellite; Payload.

I. Introduction

CubeSats are a class of nanosatellites that use a standard size and form factor. The standard CubeSat size uses a "one unit" or "1U" measuring 10x10x10 cms and is extendable to larger sizes; 1.5, 2, 3, 6, and even 12U. Originally developed in 1999 by California Polytechnic State University at San Luis Obispo and Stanford University to provide a platform for education and space exploration. The development of CubeSats has advanced into its industry with government, industry, and academia collaborating for ever-increasing capabilities. CubeSats now provide a cost-effective platform for science investigations and new technology demonstrations [1].

This CubeSat is the product of the cooperation of the Alexandria Higher Institute of Engineering and Technology students and the Egyptian Space Agency. The Egyptian Space Agency seeks to prepare student cadres in the satellites technology field to enable Egypt to take this important technology and lead in it. Therefore, the Egyptian Space Agency launched the Egyptian Universities satellite project, and our CubeSat, which will be explained later, is among the outputs of this project.

We designed and implemented an onboard computer **OBC** for a CubeSat. The project is divided into two parts, satellite, and ground station. The ground station is hosted over a computer application on a laptop.

II. CubeSat Onboard Computer

The On-Board Computer (OBC) is the brain of the satellite. It is the subsystem that acts as a bridge that connects the other subsystems with each other. It supervises many of the tasks that are done by the different subsystems of satellite, performs housekeeping and monitoring to ensure the health, the status of those subsystems, and communicates with the ground station to send the required telemetry data and satellite status [2].

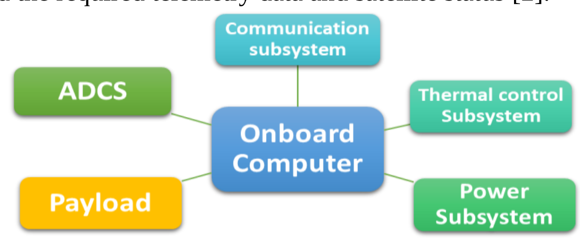

Figure II. I (CubeSat Subsystems)

A. *CubeSat Modes of operation*

- **Detumbling Mode:** It is right after the launching of the satellite into a stable orbit and works to stabilize the orientation of the satellite using the onboard. ACDS afterward the beacon is initialized and awaits further commands from the ground station.

- **Stand-by Mode**: It is the satellite recharging and waiting for the commands of the ground station where the next step is to schedule an imaging order.

- **Communication session:** When the CubeSat becomes in the range of the ground station's antenna a communication session is maintained to upload the telecommands to the CubeSat and receive telemetry data.

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- **Imaging Mode:** In this mode, the OBC gives the payload the required power and position to obtain high-resolution detailed images of the specific ground area within the specified parameters.

- **Download Mode:** After the CubeSat performs the required mission/order, it downloads the data to the ground station.

- **Failure & safe mode:** When the satellite regrettably goes through some errors or failures that compromise the mission's integrity and so it goes to safe mode to prevent cascading failures and awaits future repairs. In the case of systems made up of many different parts, it is necessary to develop a consistent coding system that uniquely identifies parts and related failures, to increase the comprehensibility of the analyses.

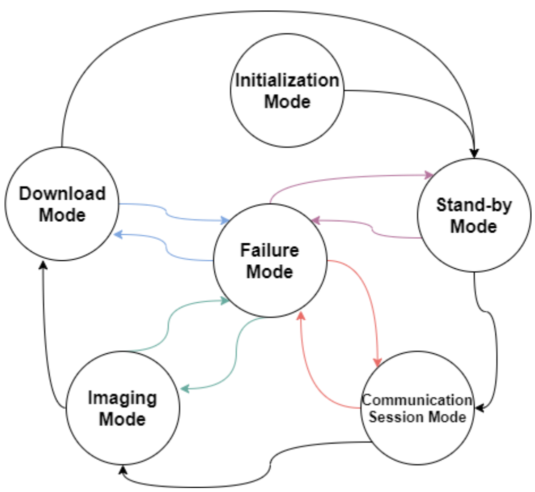


*Figure II.II (CubeSat Operation*Modes)*

B. *OBC Functions*

- Telemetry data gathering.
- Intercommunication between the subsystems.
- On-board time synchronization.
- Failure detection and recovery.

III. Project Model Approach

A. *CubeSat Structure (3D Printing)*

We chose a modular design of a one- and two-unit CubeSat which allowed us to easily assemble, disassemble and reach the internal components of the prototype, also this design gave us the ability to add more printed circuit boards carrying more subsystems if needed. The design was fabricated by 3D printer using a high-quality filament (Esun PLA+) which toughness is 10 times more than regular PLA. 3D printing specifications are:

- Nozzle diameter 0.4 mm
- Hot end temp 115 C
- Heated bed temp 55 C
- No cooling or supports.
- Slicer software settings (Cura)
- Infill density 80%
- Infill pattern Grid
- Shell 3 walls
- Top and bottom 3 layers

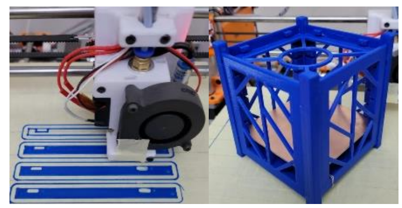


Figure IV. I (1 U CubeSat)

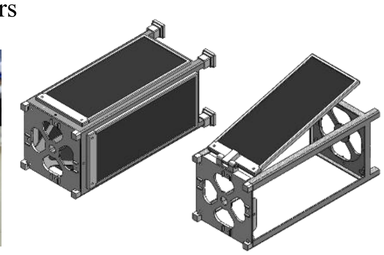
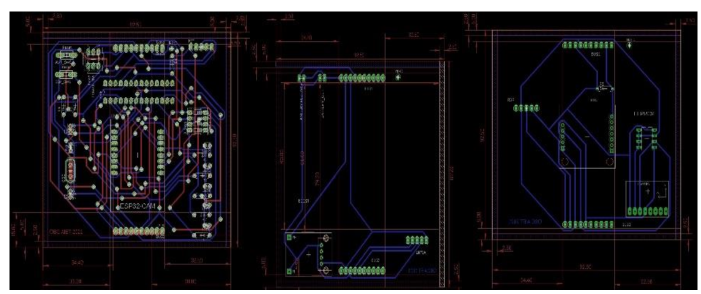


Figure IV.II (2U CubeSat)

B. *CubeSat Hardware (PCBs)*

Our PCB design is a self-nesting stack consisting of three single-layered boards each acting as a subsystem or more. The design is easy to manufacture, develop, trace errors in the system and each board has a specific function so it can be individually upgraded, developed and the most important feature in our design is the modularity of the system.



OBC Layout PCB1 *EPS Layout PCB2* *Payload Layout PCB3*

Figure IV.III (CubeSat Hardware Layout)

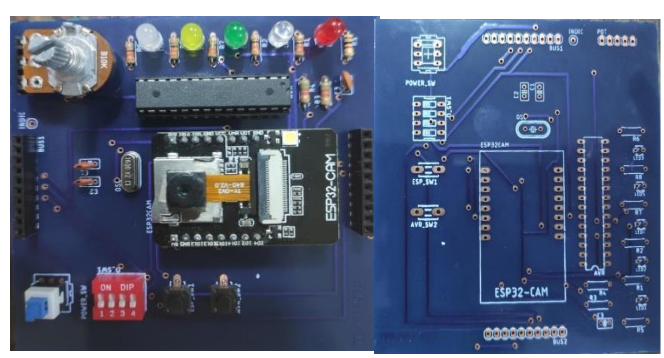


Figure IV.IV (OBC Hardware)

C. CubeSat OBC Architecture

We used an AVR microcontroller which acted as the onboard computer and sensors such as IMU, Temperature, Radar, BMS, and ESP32 Cam to act as satellite subsystems. The microcontroller is responsible for gathering the data of all sensors, organizing, and storing it in memory. The all-software code is run over a real-time operating system called FreeRTOS. When a satellite is within ground station range, the ground station will send telecommands to the satellite, then analyzes them to send the required telemetry data to the ground station.

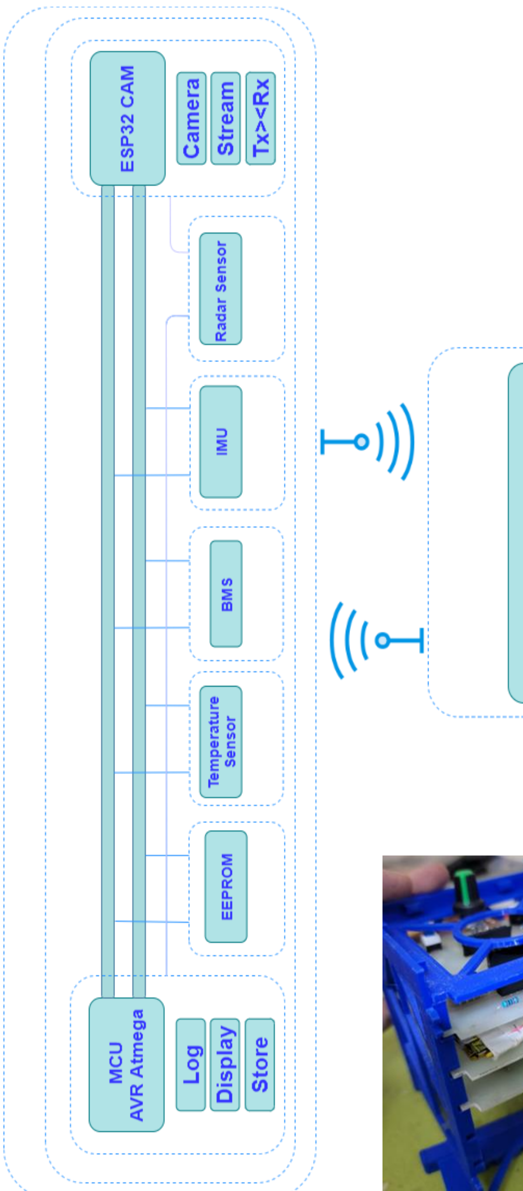


Figure IV. V (OBC Architecture)

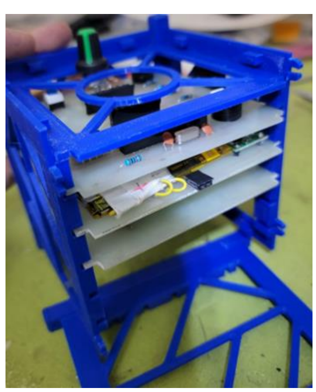


Figure IV.VI (OBC Structure)

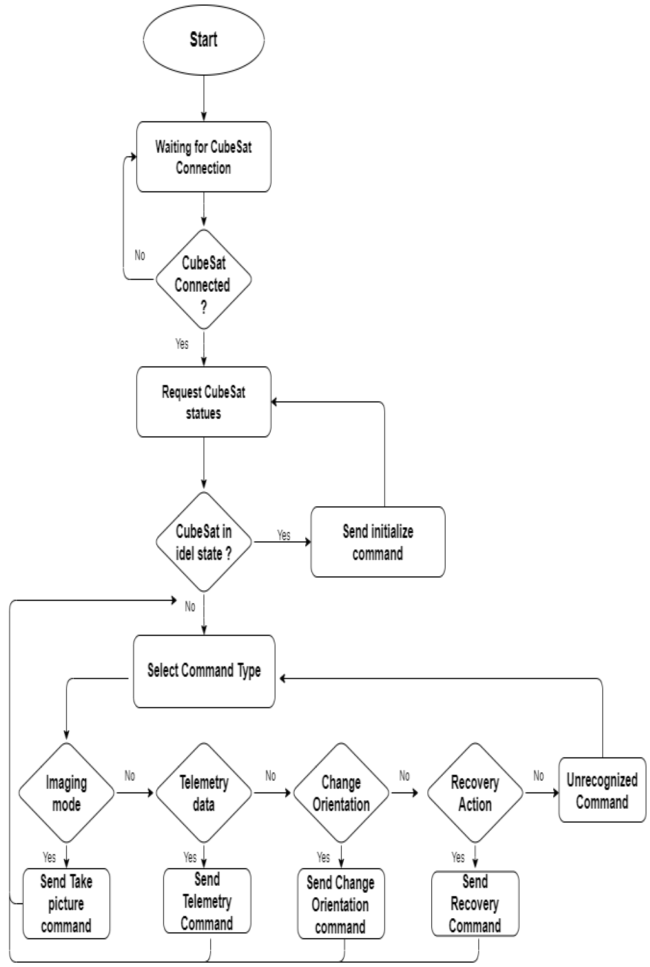


Figure IV.VII (Software Code Flowchart)

D. Ground Station

The ground station is a Web application hosted on a laptop. The code works as follows, once the microcontroller is initiated and is set up the ground station initiates a server handler that waits for a client's request, in our case an end device that connects to the CubeSat, to connect to it wirelessly, there the ESP32CAM acts as the communication subsystem, using its wireless communication capabilities and it's WIFI antenna. Once the client connects to the IP address of the board, the server forwards it the necessary files to properly display the webpage which are stored on internal memory for ease of access and quick response-in contrast to storing it on an SD card, once uploaded the webpage is displayed to the user and displays live telemetry updates from the CubeSat.

Figure IV.VIII (Ground Station)

E. *CubeSat Mission Analysis*

Mass Budget	
CubeSat Structure	**120 g**
AVR MCU	**2.16 g**
Radar Sensor	**3 g**
MPU6050	**2.1 g**
ESP32 Camera	**20 g**
Battery	**151 g**
Boost Converter	**11.79 g**
EEPROM	**0.1 g**
Temperature Sensor	**22 g**
Total CubeSat mass	**332.15 g**

TABLE IV.I (MASS BUDGET)

Power Budget		
AVR MCU	**5 V**	**0.3 mAh**
Radar Sensor	**5 V**	**3 mAh**
MPU6050	**5 V**	**3.9 mAh**
ESP32 Camera	**5 V**	**310 mAh**
EEPROM	**5 V**	**3 mAh**
Temperature Sensor	**5 V**	**10 mAh**
Total CubeSat Power	**1655 mWh**	

TABLE IV.II (POWER BUDGET)

Cost Budget	
CubeSat Material	**155 EGP**
3D printing & PCB manufacturing	**250 EGP**
AVR MCU	**60 EGP**
Radar Sensor	**40 EGP**
IMU (MPU6050)	**70 EGP**
ESP32 Camera	**400 EGP**
Battery	**200 EGP**
Boost Converter	**25 EGP**
EEPROM	**30 EGP**
Temperature	**60 EGP**
USB/TTL converter	**60EGP**
Total CubeSat mass	**1350 EGP**

TABLE IV.III (COST BUDGET)

IV. CONCLUSION

We designed and implemented an onboard computer for a CubeSat. The project can be divided into two virtual parts, satellite, and ground station. We used an AVR microcontroller which acts as the onboard computer and sensors such as IMU, temperature, radar, BMS, and ESP32 CAM to act as satellite subsystems. The ATMega328 is responsible for gathering, organizing storing, logging, fetching the data back, and displaying it on the data on the serial monitor. When a satellite is within the ground station range, the ground station will connect to its IP, then the satellite sends the required files to display the ground station's webpage.

The fabricated PCBs and 3D printed CubeSat body to house our onboard computer unit and the 3-layered PCB to shield our components, keeping in mind the weight and dimensional constraints of the whole system.

This prototype is an engineering model that can be developed and added until it becomes a real CubeSat that can be launched into space and relay data to be later converted into useful information and visuals.

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