Design and Implementation of 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 stm32f429zi microcontroller which acts as the onboard computer and sensors such as dc current, temperature, *gyroscope*, *ESP CAM*, ***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 laser machine 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].

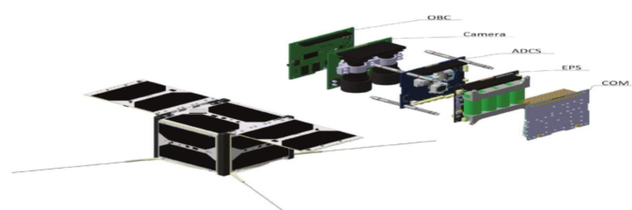


Figure II. I (CubeSat Subsystems)

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.

- **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.

B. *OBC Functions*

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

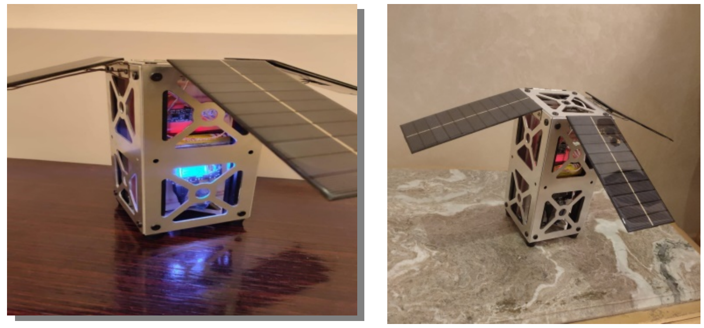
III. Project Model Approach

A. *CubeSat Structure (laser machine)*

We chose a modular design of a 2U 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 printing using a high-quality aluminium metal

Laser machine 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

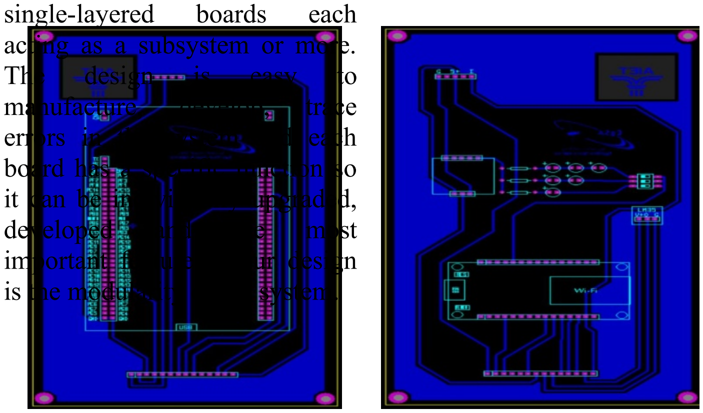


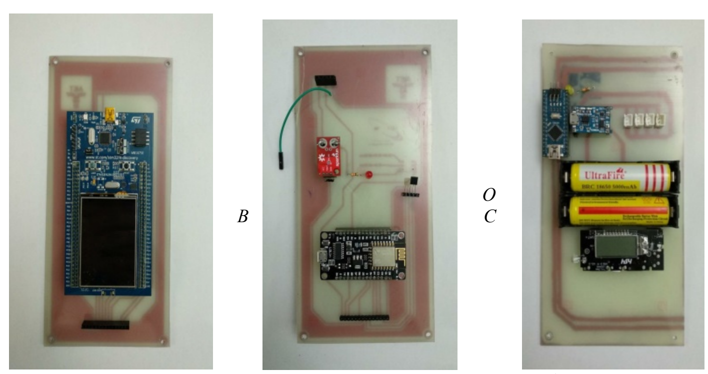
- - Top and bottom 3 layers

Figure IV.II (2U CubeSat)

B. *CubeSat Hardware (PCBs)*

Our PCB design is a self-nesting stack consisting of three single-layered boards each ac[...]ng as a subsystem or mo[...]e. Th[...] design is easy to ma[...]nufacture [...] trace er[...]rs [...] each bo[...]rd h[...] [...]o it [...]an be [...] d, de[...]veloped [...] st im[...]portan[...] [...]n is [...]he mod[...] system.





Layout PCB1 *EPS layout PCB2*

Figure IV.III (CubeSat Hardware Layout)

OBC board PCB1 *EPS and payload PCB2* *power board PCB3*

Figure IV.IV (OBC Hardware)

C. CubeSat OBC Architecture

We used an stm32f429zi microcontroller which acted as the onboard computer and sensors such as current, temperature, gyroscope, ESP CAM, 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

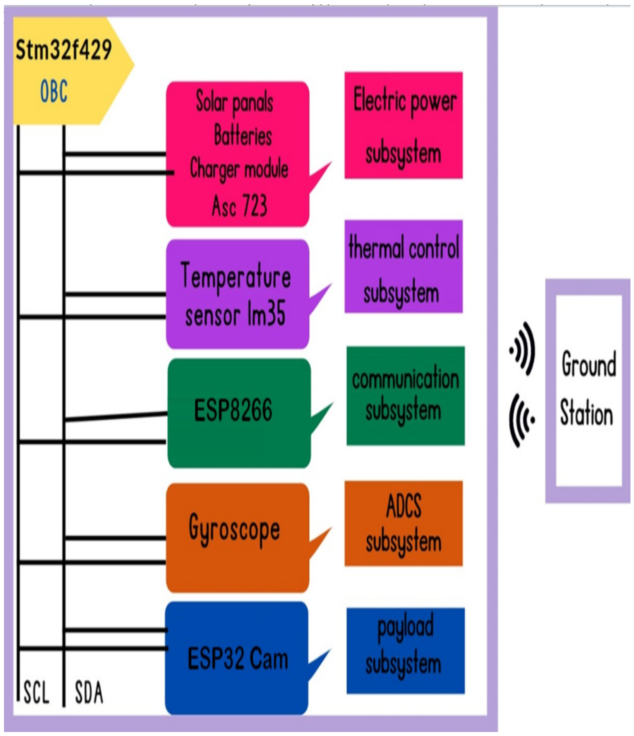


Figure IV (CubeSat lite OBC Architecture)

Figure IV. V (OBC Architecture)

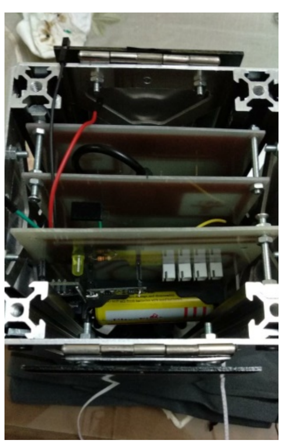


Figure IV.VI (OBC Structure)

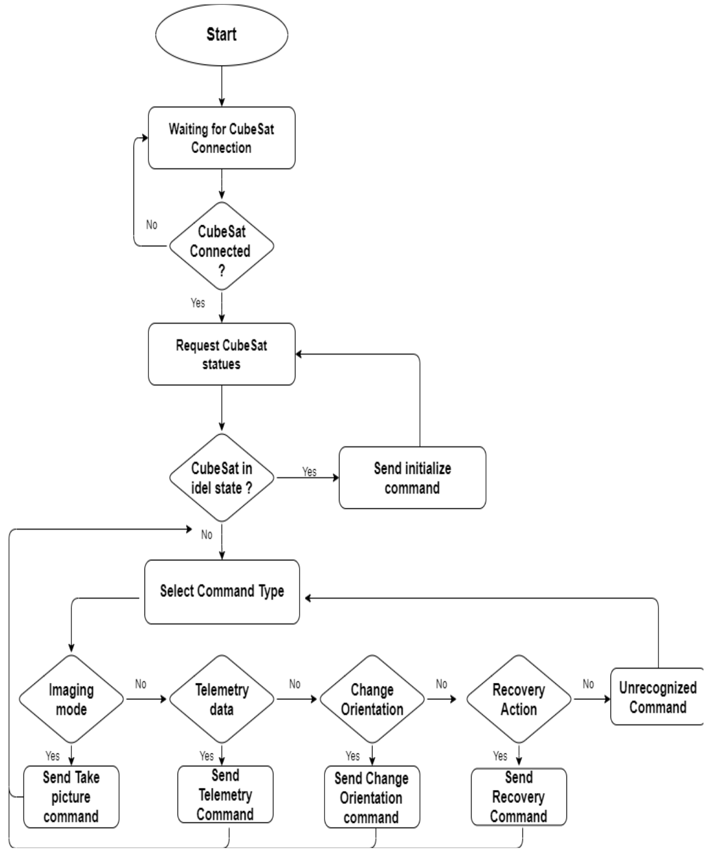


Figure IV.VII (Software Code Flowchart)

D. Ground Station

The ground station is a console application software or web page that simulate the behavior and functionality to a certain degree of a real ground station system. The code works as following; once the microcontroller (STM32F429) is initiated and is set up the ground station initiates a server handler. In our case an end device that connects to the Cube Sat, to connect to it wirelessly, there the ESP8266 module acts as the communication subsystem. Using its wireless communication capabilities and its 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 an internal memory for ease of access and quick response-in contrast to storing it on an SD card or other storage mediums-, once uploaded the webpage is displayed to the user and displays live telemetry updates from the Cube Sat ,

The Cube Sat listens for telemetry requests and responds with the requested data to be later displayed in its right place on the webpage, the data fetched from the Cube Sat comes from the various sensors around the satellite the IMU presents inertial measurements and very accurate temperature readings so it's regularly being requested for data at a rate of 6 times per minute for each of the sensor. The delta of the temperature is and the inertial data which must be updated frequently to capture the satellite's every slight move not only for its importance to accurately predict but also to present the real life representation of the satellite and relay it down to the ground station to be visualized on the ground station's webpage's Cube Sat live representation.

The webpage represents the following live data

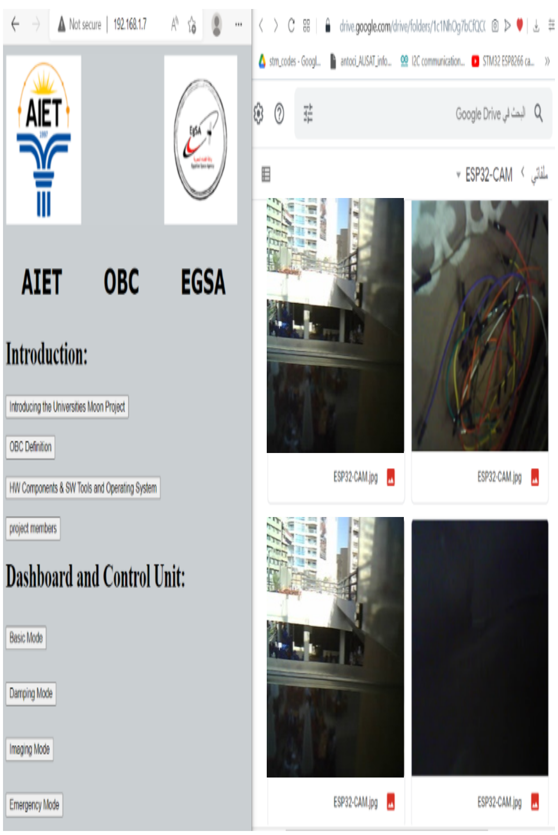
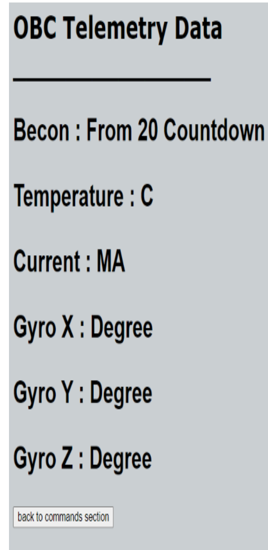


Figure IV.VIII (Ground Station)



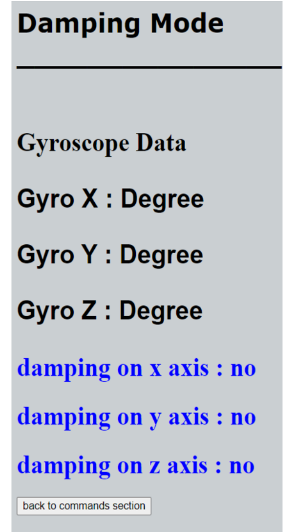


Figure IV.IX (Ground Station)

Normal mode **Figure4. 32.Detumbling mode**

E. *CubeSat Mission Analysis*

TABLE IV.I (MASS BUDGET)

Components	Mass Values
ESP8266	15 g
Current Sensor	4 g
ESP32 cam	10 g
Temperature Sensor	1 g
STM32F429	60 g
Arduino uno	27 g
aluminum cube	500 g
Boards	200 g
Total Mass	817 g

TABLE IV.II (POWER BUDGET)

Components	Voltage Values	Current Values
ESP8266	5 V	12mA
Current Sensor	5 V	9mA
Temperature Sensor	5 V	10mA
ESP32 cam	5V	20mA
Gyro	5V	85mA
STM32F429	5V	85mA
Arduino uno	5V	40mA
Total CubeSat Power	1245mw	

TABLE IV.III (COST BUDGET)

Components	Price
stm32f429zi	1200 EGP
aluminum cube	3000 EGP
PCB manufacturing	800 EGP
Current sensor	200 EGP
Esp8266	130 EGP
ESP32 Camera	320 EGP
Battery	200 EGP
Temperature sensor	100 EGP
arduino uno	350 EGP
Total CubeSat mass	6300 EGP

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 laser machine 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.

ACKNOWLEDGMENT

We express our sincere gratitude to Alexandria Higher Institute of Engineering &Technology and Egyptian Space Agency for allowing us to conduct this graduation project under their auspices.

As supervisors

Dr. Mohamed Al-Amir, Dr. Hasnaa Elarwash, and Eng Mahmoud

supported us through the stages of this work. They always supported us with constant encouragement and supervision, despite their busy schedules. Without their coherent and illuminating instruction, this project would not have reached to this stage.

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