OPTIMISATION OF CONTINUOUS DEVELOPMENT FROM FLATSAT TO 3D CUBESAT - A NOVEL OVER-THE-AIR SOLUTION

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1. Background

Cube Satellites (CubeSats) are preferred for their low cost and short development cycles compared to large-scale satellites. Within the industry-standardised CubeSat development process, multiple models of the CubeSat are developed and put through tests that simulate the harsh space environment.

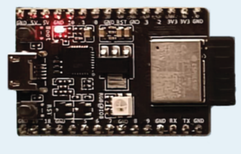
2. Issue

For testing of assembled 3D form factors, which can be as small as 1U (10cm x 10cm x 10cm), troubleshooting is especially difficult. The complexity of reassembling miniature and hard to access mechanical/thermal structures, payloads and subsystems push some developers to overlook subsystem-level tests. [1]. This leads to either more time spent disintegrating the fully assembled CubeSat when issues are surfaced during tests; or mission failure.

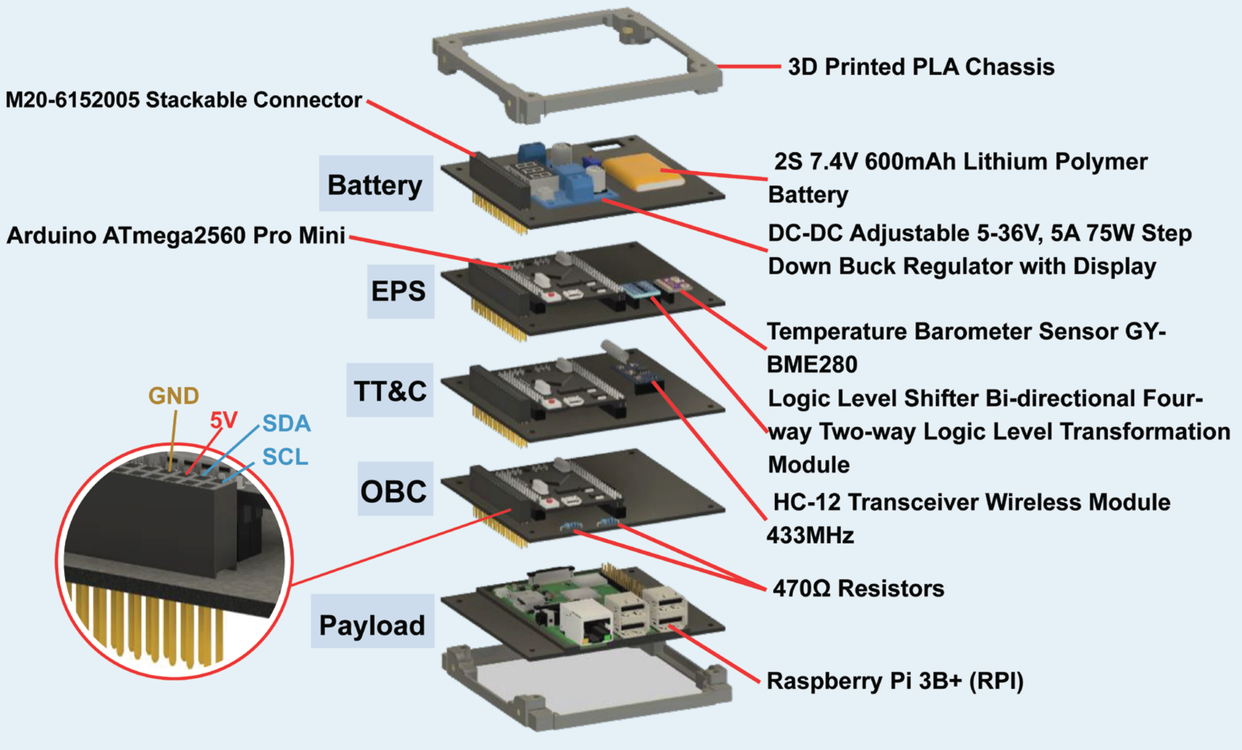
3. Objectives

To validate the integration of an ESP32-C3 development board for Over-The-Air (OTA) debugging thus significantly optimising CubeSat development by:

1. Decreasing development time
2. Minimising hardware alterations thus reducing points of failure
3. Keeping costs low

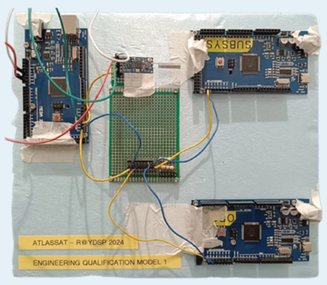


4. Bill of Materials and 3D Model



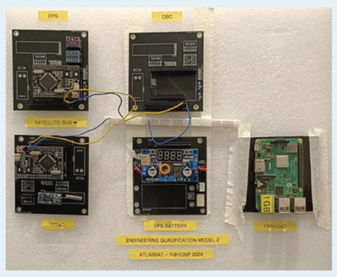
5. Development of Qualification Models (QMs)

Similar to industry practices, the QMs were developed and tested using wired debugging. The three QMs were developed for different stages of testing as such:



Qualification Model 1

Testing of Commercial Off the Shelf parts and preliminary code to ensure functionality.



Qualification Model 2

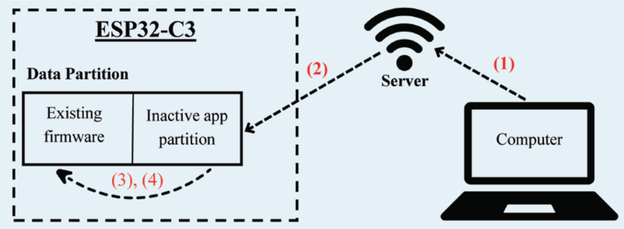
FlatSat: testing of Printed Circuit Boards subsystems are able to replicate the output from QM1.

Qualification Model 3

Final stage of testing with fully assembled 3D CubeSat.

6. Integration of ESP32

Two ESP32-C3s were used for the OBC and TT&C subsystems. Once both the remote computer and ESP32 are connected to the Local Area Network (LAN), the OTA solution undergoes the following steps:



(1) Code from the remote computer is uploaded via a firmware file hosted on the server.

(2) The ESP32 then downloads the firmware in parts and writes it to the inactive app partition.

(3) A checksum ensures that the firmware has been accurately downloaded, which triggers the partition to be written as the new active partition, leaving the other open for firmware updates.

(4) Upon writing the partition, the ESP32 is rebooted and the new firmware is run.

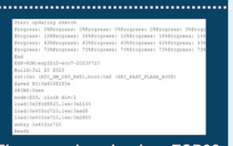
7. Results and Applications

It was verified that the setup:

1. Requires no alteration of hardware, except for the initial connection of the ESP32 with the LAN.
2. Can be readily integrated with existing setup.
3. Is able to replicate expected code output.
4. Has multiple checkpoints to indicate progress of code upload (from the terminal of the remote computer and ESP32).

Images of the progress bar in various stages of OTA upload:

Remote upload



Firmware download on ESP32

8. Applications

For CubeSat development, the OTA solution saves time:

- Disassembling and reassembling mechanical components in the FlatSat or the 3D assembled CubeSat.
- Removing a point of failure during development, as no hardware is altered after being verified to work.

In general, the OTA solution can be used in clean room environments and the development of complex systems, where handling of fragile hardware should be avoided. University students, who often work on educational CubeSats, can also integrate the ESP32 as a low-cost and time-effective debugging solution.

Advantages of integrating the ESP32-C3 chip include:

- Reliable: well-documented, industry-grade stress tests on the chip's thermal and Radio Frequency specifications remove the need for developers to test the chip before integrating it. It can also operate in extreme temperatures for long durations. [2]
- An alternative processor: the ESP32 chip is compatible with multiple communication protocols and can be directly embedded on the PCB in order to meet space requirements in the CubeSat.

9. Future Work

- Using a Field-Programmable Gate Array (FPGA) board to implement OTA via logic gates and lookup tables.
- CubeSats can make use of existing FPGA boards to wirelessly debug, without integrating a new component.
- Using the same parts for remote software updates pre- and post-launch.

OR

- Adapt the OTA solution for post-launch code updates.
- The verification of the chip's functionality in space fully justifies its integration into CubeSat's designs as code updates can be performed both pre- and post-launch.
- This entails testing of the ESP32-C3 chip as per ASTM E-595 testing guidelines.

10. Additional Content

System overview, Subsystem descriptions and PCB Schematic

Program flow, Subsystem functions and Protocols

Access to project source code

References:
[1] C. Venturini, B. Braun, D. Hinkley, The Aerospace Corporation, and Greg Berg, "Improving Mission of CubeSats," conference-proceeding. [Online]. Available: https://s3vi.ndc.nasa.gov/ssri kb/static/resources/Improving%20Mission%20Success%20of%20CubeSats.pdf
[2] Espressif Systems, "ESP32-C3 Series datasheet," 2021. [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32-c3_datasheet_en.pdf