SPACE TECHNOLOGIES TRAINING AND CAPACITY BUILDING IN TUNISIA THROUGH THE FACT PROJECT

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The emergence of experimental nanosatellites, especially CubeSats, for space exploration and experimentation, gives low-cost space access to emerging countries such as Tunisia. In fact, CubeSats can be easily developed and fabricated since their components are widely available and are relatively not very expensive. Moreover, CubeSats have versatile applications in different important domains, such as communications, remote sensing, border surveillance, environmental risks monitoring and mitigation, etc.

In this context, the project Fabrication and Applications of CubeSats in Tunisia (FACT) was launched since the end of 2018 for a period of 4 years. The purpose of this paper is to present the FACT project and its main outcomes related to space education and capacity building. Specifically, the paper presents the main research and engineering activities carried-out by researchers and students within the framework of the project and the major results found.

Key Words: Space technologies, Space education, Space capacity building

1. Introduction

During the last two decades a lot of progress in the development of nanosatellites, mainly the CubeSat formfactor, was made. This technical advancement can give low-cost space access to emerging countries such as Tunisia. In fact, CubeSats can be easily developed and fabricated since their components are becoming more and more available at relatively low prices compared to larger satellites. Additionally, CubeSats have versatile applications in different important domains, such as communications, remote sensing (for agriculture and territorial management for example), border surveillance, environmental risks monitoring and mitigation, etc.

On another hand, most space applications are within the scope of the Tunisian National Research Priorities. In fact, every space application involves one or more national priorities. As an example, space technologies and particularly CubeSats would help in the digital and industrial transition (development of CubeSat prototypes and subsystems), securing energy, water, and food (space surveillance), Education (new study fields). The space segment would also help in the implementation of new applications, such as smart cities, smart agriculture, smart transportation, IoT, etc. without the dependence on other countries. For all these reasons, it was important for Tunisia to start its space journey by developing and testing CubeSats, which have a high Technology Readiness Level (TRL). This would also provide important capacity building in space technologies for students and engineers, which in turn would help in creating new jobs and new student profiles.

In this context, many national research initiatives in the space domain were made since 2011 [1-10] mainly by researchers from the Microelectronics and Instrumentation Laboratory (μEi), Faculty of Sciences of Monastir, Tunisia, and some other research institutions. In the same context and for capacity building purposes, two summer-schools about CubeSat subsystems design were organized respectively in 2012 and 2014 for the researchers of the μEi laboratory and other parties interested in the space domain. The speakers in these 2 events were experienced professors in CubeSat design and development from Germany, Turkey, and Spain. Additionally, within the context of bilateral cooperation between Tunisia and Turkey, the project "Development of Intelligent Control Modules for Nano Satellites" was carried-out between 2016 and 2018 [11]. The project involved two teams from Tunisia and one team from Turkey.

Then, in 2018, and to further advance space research in Tunisia, the nationally funded project: Fabrication and Applications of CubeSats in Tunisia (FACT) was launched for a period of 4 years (expected to finish by the end of December 2022). The project is carried-out by a consortium of four institutions and is coordinated by the Center for Research on Microelectronics and Nanotechnology (CRMN) of Sousse, Tunisia. The other project partners are:

- The private company, Enova Robotics, Sousse, Tunisia,
- The National Center for Remote Sensing and Mapping, which is a public research center under the authority of the Ministry of Defense
- The Microelectronics and Instrumentation Laboratory.

The FACT project is mainly funded by the Tunisian Ministry of Higher Education and Scientific Research in the framework of the PAQ PROMESS national research project financing program. This program is intended to modernize the Tunisian higher education system through research development within universities and research centers.

The objective of this paper is to present an overview about the FACT project and its main outcomes related to space education and capacity building in Tunisia. Specifically, the paper describes the main research and engineering activities carried-out by researchers and students within the project and their major findings.

2. Project Objectives

The following objectives were set to be achieved by the FACT project:

- Capacity building of engineering, masters, and Ph.D. students in emerging space technologies.
- Acquisition and installation of CubeSat mounting and testing facilities that can be used for collaboration on other industrial aerospace projects (national or international).
- Help in the establishment of new aerospace companies (national or international) in Tunisia by providing qualified engineers in space technologies.
- Contribution to reinforce national Research and Innovation activities related to space technologies.
- Development and fabrication of the first Tunisian university CubeSat prototype using national skills, which will give access to important international financing and collaboration on bigger projects.
- Procurement of important concepts of space technologies that have high economic added value applications at relatively low costs.
- Management of the research collaboration between the members of the heterogenous consortium composed of a research center, a higher education and research institution, a private company, and a Ministry of Defense research center.

3. Expected results

During the preparation phase of FACT, five main results were set to be accomplished by the end of the project. The expected results are as follows:

- R1: Installation of a CubeSat mounting facility
- R2: Installation of a CubeSat testbed facility
- R3: Development of a 1U CubeSat prototype
- R4: Capacity building of researchers and students in the space domain
- R5: Communication, dissemination, and sustainability of the project

4. Personnel involved in the FACT project

Eight (8) researchers, three (3) engineers, and sixteen (16) students participated in the execution of the different work packages of the FACT project. The students involved were from various fields, such as: electrical engineering, computer engineering, communication engineering, and electromechanical engineering. They were preparing diverse types of degrees ranging from License degree (BS equivalent) to Ph.D. degree. Table 1 details the distribution of the different people involved in the project.

Table 1. Distribution of people involved in the project.

Category	Field of studies	Number
Researcher	Electrical engineering	2
	Electronic and microelectronic	3
Early-Stage Researcher	Telecommunication	1
	Microelectronics	2
Engineer	Mechanical	1
	Geomatics	2
Other Graduate Student	Microelectronics	3
	Computer Engineering	1
	Electrical Engineering	2
	Information and Communication Technologies	2
Undergraduate Student	Electrical Engineering	3
	Computer Engineering	1
	Electromechanical Engineering	4

5. Project achieved outcomes

In this paper, only the outcomes relative to results R2, R3, and R4 will be presented since they are closely related to CubeSat development and space technology capacity building. The main accomplished work in this context is detailed in the next sections.

5.1. CubeSat prototype design

The mission of the CubeSat prototype that is being developed within the FACT project is to test a Software Defined Radio (SDR) based communication system. This reconfigurable system will allow signal reception, storage, and forwarding from multiple transmitters working at different frequencies and using different modulation schemes.

To carry-out the set mission, a 1U formfactor CubeSat platform was selected. The platform is composed of the following subsystems:

- Aluminum structure
- Onboard computer (OBC) based on the ARM Cortex M7 STM32H7 microcontroller.
- Electrical Power System (EPS) including solar panels, lithium-ion batteries, and power conversion and distribution circuitry.
- Attitude Determination and Control System (ADCS) composed of three-axis gyroscope, three-axis magnetometer, coarse sun sensor, and three-axis magnetorquer. The ADCS is controlled by the microcontroller of the OBC.
- Communication System working in the UHF band (435MHz to 436MHz). This system will be used for Telemetry, Tracking and Command (TT&C).

The 1U CubeSat platform was ordered at a CubeSat subsystems supplier and it will be integrated and tested at the CRMN mounting and testing facilities that were installed in the beginning of the FACT project (i.e., results R1 and R2). Fig. 1 shows some of the ordered subsystems and Fig. 2 shows a 3D model of the integrated 1U platform.

(a) (b) (c)

Fig. 1. 1U CubeSat subsystems: (a) OBC, (b) EPS, (c) Magnetorquers

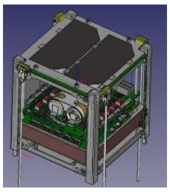


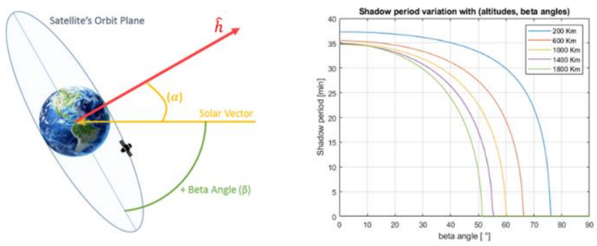
Fig. 2. 3D model of the integrated 1U CubeSat platform (side solar panels not shown)

The CubeSat payload is an FPGA based SDR that can work at a frequency band ranging from 100MHz up to 1GHz. More details about the SDR communication system are given in 5.5.

5.2. Electrical Power System related projects

To ensure a successful CubeSat mission that meets the set requirements, the EPS should be correctly designed and tested. The major role of the EPS is to provide the required power to all subsystems regardless of the illumination conditions, which change while the CubeSat is orbiting the earth. Optimum power delivery is accomplished by storing power during the sunlit periods and then restoring it during the eclipse periods.

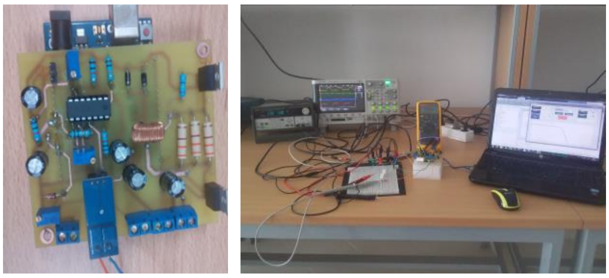
In this context, a study was done by a Ph. D. student to investigate the variation of the satellite's illumination period while in orbit. It was found that the sunlight period is mainly affected by the satellite's beta angle and altitude as shown in Fig. 3. Therefore, these parameters should be carefully selected to minimize the eclipse periods and thus maximize the satellite's power production.



(a) (b)

Fig. 3. Eclipse period variation: (a) Beta angle, (b) Shadow period variation with altitude and beta angle

To easily test the EPS behavior under different power consumption modes, illumination scenarios, and battery state-of-charge, two simulators were designed and constructed by two graduate students. These simulators are a Solar Array Simulator (SAS) and a Battery Simulator (BAS) that were made based on [12] and [13]. These simulators consist of two power electronic circuits that are controlled by Graphical User Interfaces (GUI). Electronically, the simulators behave, respectively, like a solar array and a battery according to user-selected parameters. Fig. 4 shows the developed SAS circuit along with its control and measurement setup.



(a) (b)

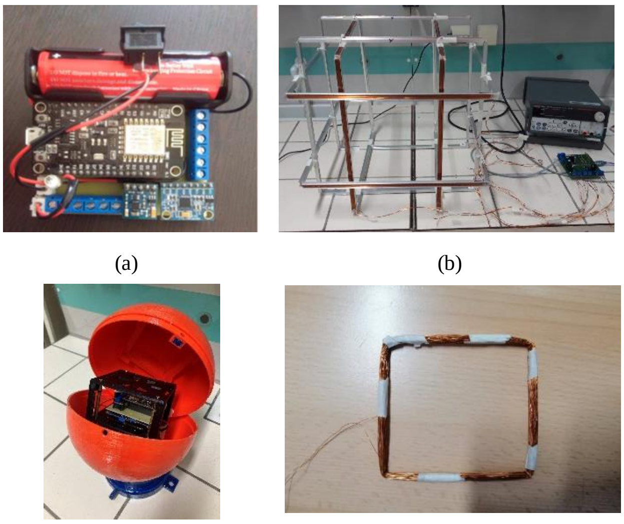
Fig. 4. SAS: (a) Developed circuit, (b) Control and measurement setup

5.3. Attitude Determination and Control System projects

The ADCS is a very important system in a CubeSat, since it has a critical role in the mission success, and, if well designed, it contributes to increasing the spacecraft's service-life.

Within FACT, four projects related to ADCS were conducted by a group of undergraduate and graduate students:

- Attitude acquisition module with autonomous power and wireless data transmission. The system, shown in Fig. 5.a, is composed of a three-axis magnetometer, gyroscope, accelerometer, and WiFi data transmission. The system also includes a GUI for real-time attitude data acquisition and display.
- Helmholtz cage for earth magnetic field simulation. It is constructed with an aluminum frame (Fig. 5.b), and it can deliver a magnetic field strength of ±120µT on each axis.
- Air-bearing sphere for frictionless rotation on 3 axes. The system is built by 3D printing, and it can hold a 1U CubeSat as depicted in Fig. 5.c.
- Air magnetorquers (Fig. 5.d) providing a magnetic moment strength of 0.32 Am^2 with a power consumption of 1W and a mass of 30g.



(a) (b)

(c) (d)

Fig. 5. ADCS related projects: (a) Attitude acquisition, (b) Helmholtz cage, (c) Air-bearing sphere, (d) Air magnetorquer

5.4. CubeSat mechanical structure prototype

To test the different subsystems of the CubeSat and ensure their correct operation, a 1U CubeSat mechanical structure prototype was designed by an undergraduate student and fabricated with a 3D printer. The structure can hold commercial or in-house made subsystems. Fig. 6 shows the designed 3D model and the fabricated structure.

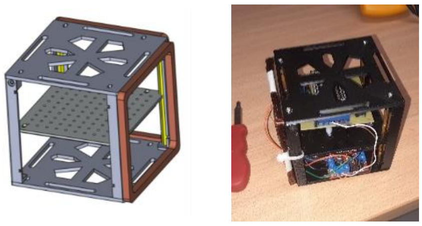


Fig. 6. 1U CubeSat mechanical structure: 3D model and constructed prototype

5.5. Payload related projects

As stated in the previous section, the CubeSat payload is a SDR based communication system that will allow signal reception from multiple transmitters working with different frequencies and modulations. The SDR is a configurable wireless communication system whose main radio functionalities are implemented in software on an embedded system instead of hardware.

To test this concept, a Ph. D. student studied and successfully implemented a SDR bridge [14,15], which receives a LoRa signal sent from a beacon with a given frequency, then forwards it with a different frequency to a LoRa receiver at the User's end. The block diagram of the SDR bridge is presented in Fig. 7.

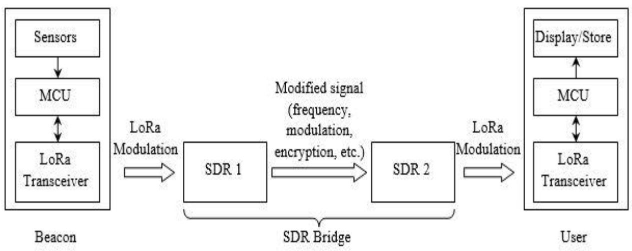
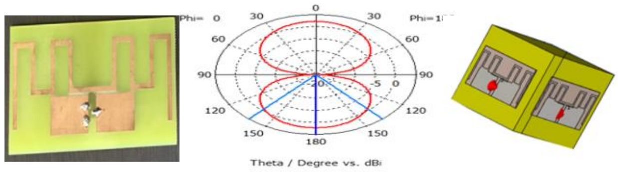


Fig. 7. SDR bridge simplified block diagram

For signal transmission, the SDR needs an antenna with a high performance and reduced size. To reach this objective, a miniaturized planar meander line antenna for CubeSat communication was designed and tested by a Ph. D. student [16]. The proposed antenna works at the LoRa frequency of 920MHz and has a small footprint of 50mm x 80mm x 1.635 mm. Experimental results showed that the antenna has an omnidirectional radiation pattern and a gain of 1.8 dB. Fig. 8.a and 8.b show the constructed antenna and its radiation pattern at 920MHz, respectively. As presented in Fig. 8.c, the antenna can be placed on any side of the CubeSat. Since it has a small thickness, the antenna can be placed underneath a solar panel without hindering its operation.



(a) (b) (c)

Fig. 8. Meander line antenna: (a) Constructed antenna, (b) Radiation pattern at 920 MHz, (c) Antenna placement on the CubeSat

5.6. CanSat prototype project

As part of the FACT project space capacity building activities, a CanSat prototype was developed by a group of undergraduate and graduate students. The main mission of the CanSat is to acquire temperature, humidity, atmospheric pressure, and GPS location every 2 seconds during the descent. The acquired data is transmitted in real-time by an UHF transmitter to a ground station for data visualization. Fig. 9 shows the built CanSat prototype, and its 3D printed protecting structure.

Fig. 9. Constructed CanSat subsystems and its 3D printed frame

5.7. Trainings

Trainings on space technologies are an important part of FACT. During the project lifetime, many trainings were attended by the members of the team. The main trainings were:

- The first Tunisia-China Space Tech Workshop: Mission design for remote sensing. This three-day workshop was organized at the CRMN headquarters and attended by all the project team members. The trainers in this workshop were Chinese engineers from China Academy of Space Technology (CAST).
- The two-month program Unispace Nanosatellite Assembly & Training (UNNATI) organized by the Indian Space Research Organization (ISRO) in India. This theoretical and practical training was attended by a researcher from the FACT team.
- Training Course on Earth Observation and Remote Sensing, Space Science, Law, and Policy, organized by the Italian Space Agency (ASI) in collaboration with the Kenya Space Agency and with the support of the United Nations Office for Outer Space Affairs (UNOOSA). This one-week course was attended in Kenya by a researcher from the FACT team.
- International Training Workshop on Space Technology and its Application, organized by CAST in Beijing, China. This three-week workshop was attended by a researcher from the FACT team.

It should be noted that these hands-on trainings were a good opportunity for Technology Transfer in space technology in general, and CubeSat development in particular, for the participating members of the FACT team.

6. Conclusion

In this paper, the project Fabrication and Applications of CubeSats in Tunisia (FACT) was presented. Firstly, an overview of FACT objectives and expected outcomes was given. Then, the different activities related to space technology capacity building were detailed. It is estimated that the main project objectives were achieved since many students were able to discover and start working in the space domain. Additionally, researchers were able to enhance their knowledge in nanosatellite design and development.

Finally, it should be noted that theoretical and practical training courses in Space technologies, CubeSat development, and CanSat development are scheduled in CRMN for fall 2022 as part of the FACT project. The aim of these training programs is to give a broad range of interested students an introduction on different space aspects and thus encouraging them to pursue their studies in the space field.

Acknowledgments

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