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DEVELOPMENT OF A SPACE TECHNOLOGY CAPACITY BUILDING INITIATIVE AT THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, NIGERIA

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ABSTRACT

Satellite communication is a wireless means of transmission of intelligible signals/information. When properly utilized it will bring about a great and positive development on the economic growth of any nation. The Federal Government of Nigeria made a giant step in the communication sector by launching five satellites into space: NigeriaSat-1, NigComSat- 1, NigeriaSat-2r, NigeriaSat-X and NigComSat-1R. With adequate spatial information, informed decisions can be made by stakeholders and adequate steps taken to ensure the growth of the nation. Demand for training capacity building in space technology is increasing. Unfortunately, space technology is a relatively expensive field with ongoing research for affordable training approaches. This paper presents methods of building capacity by developing Demo Satellites that receive telemetry data with radiofrequency and internet of things communication protocol. Web Dashboard was developed for remote monitoring of ground station and for exploring mobility in data communication, Localization was achieved to also track the Demo Satellites and the ground station in real-time. It is shown that the implementation of a low-cost capacity building programme is not only possible but a goal that should be aimed at. Multiple segments in the design of the schematics produced can be reused. It presents a pioneer satellite constellation prototype that displays the capabilities of a satellite in solving some of the country's challenges and creating awareness on space research and its trends.

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1.0 INTRODUCTION

Space research in the world is transforming every facet of life and has become an integral part of the world system. Its applications include accurate navigation and positioning (global navigation satellite system (GNSS) services), communication, resource management and monitoring (mining, vegetation, weather and human), security and military purposes etc (Union of Concerned Scientists, 2013; National Committee for Space and Radio Science, 2017). Spatial data and their applications have become extremely reliable data at all levels of government, industry, education and society worldwide. Space science also helps understanding the world around us and

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making the best of its potential and opportunities while seeking ways and ensuring its balance in the nature of life.

Data from space science and technology research have become an integral part of the government, industry, society and other stakeholders. The space economy is so encompassing and the definition as presented by OECD (2008) is: "All public and private actors involved in developing and providing space-enabled products and services. It comprises a long value-added chain, starting with research and development actors and manufacturers of space hardware (e.g. launch vehicles, satellites, ground stations) and ending with the providers of space-enabled products (e.g. navigation equipment, satellite phones) and services (e.g. satellite-based meteorological services or direct-to-home video services) to final users."

Research and development activities related to Space Science, Space Technology and Space Application to academia in the world is very diverse and all-encompassing. Some major areas in space research and applications include Launch Vehicles, Satellite Communication, Earth Observation, Space Science and Meteorology.

In an attempt to employ space technology as a tool to tackling some of its regional and national challenges, Nigeria established its first space agency called the National Space Research and Development Agency (NARSDA) in 2001 (Boroffice, 2008). The National Space Research and Development Act, 2001 is the primary legislation governing the operation of space-related activities. The Act established NARSDA and the National Space Council which is the highest policy-making body for space science and technological development in the country. The agency which is an offshoot of the federal ministry of science and technology was tasked with the mandate of kick-starting the country's venture into space with the ultimate goal of using the technology as a key driver for the country's socio-economic development (Aro and Adetoro, 2011).

The last fifteen years have witnessed quite some activities for the agency. In all, six satellites have been launched. The NigeriaSat-1 was the first Nigerian satellite which was built in partnership with Surrey Satellite Technologies in the UK and launched in September 2003 on board a Kosmos-3M rocket (Boroffice, 2008). The satellite within its nine years operation was used to acquire a wide range of data for geospatial purposes. The satellite was retired from service in October 2012 and was succeeded by two other satellites NigeriaSat-2 and NigeriaSat-X. Both satellites were built at Surrey Satellite Technology Limited (SSTL) by both Nigerian and SSTL Engineers. The satellites were launched in 2011 by the Dnepr launch vehicle from Russia. NigeriaSat-2 is a 300 kg Earth Observation Satellite with 2.5 m panchromatic very high resolution (Aro and Adetoro, 2011). NigeriaSat-X was developed by a team of 26 Nigerian Engineers also at SSTL. The 100 kg satellite was developed to advance Nigerian space technology and provide hands-on technical training opportunity to build the country's capacity in space engineering.

The National Space Research and Development Agency and the Federal Ministry of Science and Technology in 2004

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signed a contract with the China Great Wall Industry Corporation to develop the country's first communication satellite called NigComSat-1. The satellite launched on 13th May 2007 was projected to have a service life of 15 years (Lawal and Chatwin, 2012). The satellite, unfortunately, failed in orbit after just 18 months due to an anomaly in its solar arrays. The defunct satellite was replaced by the NigComSat-1R satellite which was successfully launched on 19th December 2011.

While Nigerian interest in space Technology is laudable, its approach has been underwhelming. All of Nigerian five satellites were built and launched outside the country (Isoun, 2008). No Nigerian university was carried along and very minimal technology exchange was realized from the university point of view. Capacity building at the university level is important if the Nigerian space program will be sustainable. Efforts must be made to emulate countries like India and Costa Rica who used their space program to build capacity at the grass root and to facilitate the growth of indigenous space industries.

1.1 The challenge with Nigerian Space Program

In the case of Costa Rica for instance, the IRAZU satellite which is the first for not only the country but for the whole of Central America was spearheaded by the Central America Association for Aeronautics and Space (ACAE) and the Costa Rica Institute of Technology (Jiménez, Jenkins, and Godínez, 2017). The involvement of the nation's top public university ensures that capacity is built to the maximum. The same cannot be said of Nigeria. Since December 2011 when NigComSat-1R was launched, space activity has been almost non-existent in the country. The initial plan of the government was to launch NigComSat-2 and NigComSat-3 in 2012 and 2013 respectively with another satellite for the military in 2015. All this has not been possible due to various reasons such as the economical state of the country, change in government and focus of the country, etc.

1.2 Space Research and Applications at the Federal University of Technology, Akure

The Centre for Space Research and Applications (CESRA), of the Federal University of Technology, Akure (FUTA) was set up in December 2008 following the approval of the University Senate in October 2008. The Centre was established with the mandate to complement the efforts of the Federal Government of Nigeria in the development and use of Space Science and Technology (SST) to enhance the socio-economic development of Nigeria (Dahunsi *et al.*, 2019).

In an attempt to alleviate the challenge of poor human capacity, the Federal University of Technology, Akure in collaboration with the National Space Research and Development Agency, Nigeria and Kyushu Institute of Technology, Japan took a giant stride in 2017 by launching the first Nigerian University Education Nanosatellite into space. This was Nigeria's first space activity since the launching of NigComSat-1R in 2011. The Nigeria EduSat-1 is a 1.33 kg CubeSat designed by students and staff of FUTA and KYUTECH to build human capacity in space-related research as well as demonstrating mainstream technology on small satellites

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(Dahunsi *et al.*, 2019).

It is however important to note that the project approach is somewhat similar to what the country has been doing in the past since the CubeSat was developed outside the country. The ultimate goal is to be able to domesticate the technology in other to encourage independent and indigenous space research in most Nigerian universities.

This paper presents efforts made by FUTA to start active, cost-effective capacity building in aerospace, sensor networks, electronics, information and communication engineering, embedded systems, etc which are all fundamental areas in space research. Demo Satellites and Unmanned Area Vehicles (UAV) were designed and implemented to teach aerospace engineering, sensor technology, measurement and instrumentation, communication, data capturing, power budgeting and embedded system technology. A low-cost ground station for a constellation of four (4) Demo Satellites was developed with a web server and web dashboard for data visualization and localization algorithm for tracking. Section II discusses the methodology while Section 11I presents the project carried out and Section IV the result of the project

2.0 METHODOLOGY

There are four prototype satellites with sensors, transceivers, positioning and data storage devices to simulate satellite data acquisition functions such as environmental monitoring, aerial mapping, localization and cellular network accuracy investigations. The prototype satellites are launched to an altitude of about 80 – 150 m above sea level by unmanned aerial vehicles (UAV). The UAVs hovers in the atmosphere for about 3 minutes, descends and lands. Telemetry data is collected by the prototype satellite and transmitted to the ground control station. The ground station receives the telemetry data, processes it and presents the analysed data to interested stakeholders.

The ground station consists of telemetry data receiver system, data conversion system and data presentation system. Integration of these subsystems gave a fully functional ground station. The ground station can receive telemetry data from Demo Satellites with a distance of 1.5 kilometres apart using radiofrequency and Internet of Things communication protocol developed. The data is converted to a human-readable format and presented through the data presentation system. These data are analyzed and shown to

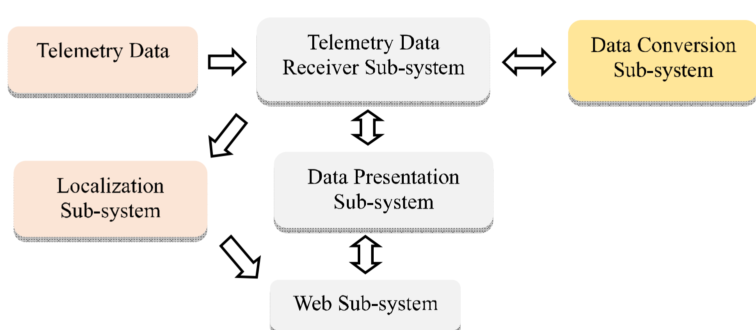

Figure 1: Block Diagram of the Ground Station for Telemetry Data

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users through the web design and development system. To monitor the satellite navigation, location data are aggregated and analysed using the localization system and display to the user through the web design and development system. Figure 1 shows the block diagram of the Ground Station Telemetry Architecture. All data are stored on the hard disk of the ground station inside a .csv file and it can easily be imported into excel and separate into columns.

The power Sub-system provides the power at different voltage level to the sensors/modules according to the manufacturers' specifications using the datasheet. The power subsystem comprises basic electrical/electronic components such as diodes, LEDs, capacitors, Li-ion batteries, SPDT switch, connecting wires, header pins.

2.1 Data Communication Subsystem

Radio Frequency signal receiver was designed using HC-12 transceiver running a proprietary algorithm for data communication through specific channels and receiving frequency which must be in synchronization with the transmitting frequency. HC-12 is an RF UART (Universal Asynchronous Receiver - Transmitter) communication module and used as an embedded wireless data transmission module. The Radiofrequency of 433.4 - 473.0 MHz, can be set in the communication channel and steps of 400 kHz, a total of 100 channels can be set. The module's maximum transmit power is 100 mW (20 dBm), and -116 dBm receiver sensitivity air of the 5000 bps baud rate, communication distance is about 1500 meters.

The HC-12 transceiver was connected to a microcontroller AVR ATMEGA 328P with a clock speed of 16 MHz for running the algorithm to receive telemetry data (in 8-bits character encoding and display the data in volts) different channels at a specific frequency and also accelerate the transmission process using 16 MHz oscillator circuit. The binary data was converted to human-readable format using the proprietary algorithm in C programming language to be displayed at the serial monitor of the Integrated Development Environment (IDE) at 9600 baud rate and running at 16 MHz clock speed for fast data conversion.

ESP8266 WiFi - IoT module running a proprietary algorithm for data communication using HTTP from DemoSAT-1. ESP8266 Wi-Fi module is a self-contained system on chip (SOC) with an integrated TCP/IP protocol stack that can give any microcontroller access to a Wi-Fi network. The transmitted data were received at the ground station using WiFi and captured in the database using the REST API and are parsed into JSON to ease sorting and further analysis. A 5.8 GHz video receiver receives the video data wirelessly and it goes through the video splitter that gives an AV output. The video converter converts the video from AV format to VGA format. Figure 2 shows the block diagram of the data communication module of the system.

The Wi-Fi module communicates with the web design and development system rule engine using Message Que Telemetry Transport (MQTT) protocol mode for the communication because of the lightweight, security and low power consumption. The IoT receiver system connects to DemoSAT-1 Wi-Fi and provides efficient transfer of telemetry data without congestion. The IoT receiver

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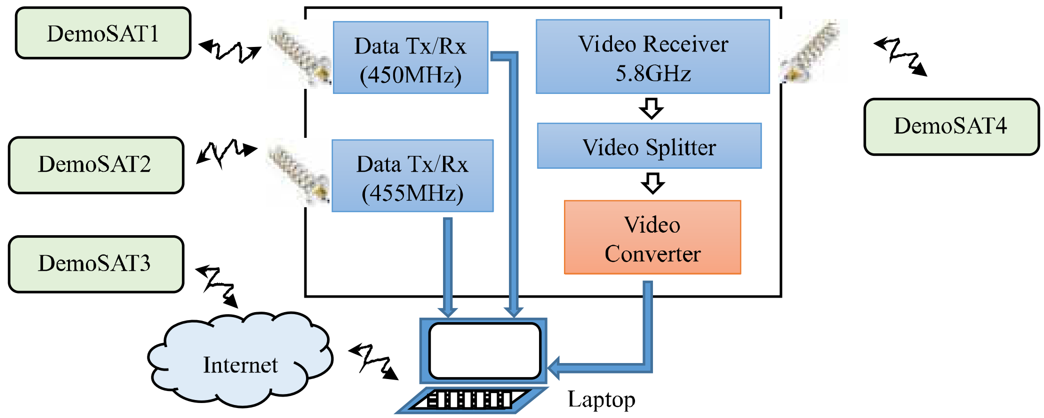

Figure 2: Block Diagram of Ground Station

system supports APSD for VoIP applications and Bluetooth co-existence interfaces, it contains a self-calibrated RF allowing it to work under various operating conditions, and it requires no external RF parts.

2.2 Environment Monitoring Demo Satellite (DemoSAT- I)

This is a representation of a real satellite on a mini scale to demonstrate environmental monitoring. Its mission is to monitor the weather conditions (temperature, pressure, humidity, air quality) of a geographical area concerning altitude and get the geographical location and time. The single-board microcontroller used is the Node MCU, an open-source IoT platform that is connected to the sensors. It includes firmware that runs on the ESP8266 Wi-Fi SoC (System on Chip). Figure 3 shows the block diagram of DemoSAT-1.

The sensors are the barometric pressure, temperature and altitude sensor (BMP 180), Temperature sensor (DHT11), Gas sensor (MQ135), Temperature and pressure sensor (DHT 11) and the GPS Module (Neo-6M). Two LiPo (Lithium Polymer) batteries of 4.2 V/2000 mAh each are connected in series to power the circuit. Decoupling capacitors (22 µf -100 µf, 50 V) are used to filter out noise. A 7805 voltage regulator steps down the 8 V Vin to 5V/1A. The LED when on indicates that the NodeMCU is powered and is supplying 3.3 V to the board. This board powers the NodeMCU and the sensors.

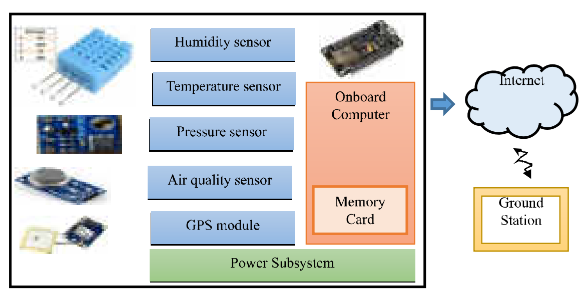

Figure 3: Block diagram of Environment Monitoring Demonstration Satellite

2.3 Camera/Imagery Demo Satellite (DemoSAT- II)

DIY OV7670 300KP VGA Camera module was used for video capturing. A 5.8 GHz video receiver receives the video data wirelessly and it goes through the video splitter that gives an AV output. The video converter converts the video from AV format to VGA format.

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2.4 Earth Habitability Monitoring Demo Satellite (DemoSAT- III)

The DemoSAT- III demonstrates monitoring of the environment concerning health. Its mission is to monitor received signal strength (RSS) using SIM800a, proximity (**HCSR04**), dust (GP2Y1010AU0F), altitude, and location (GPS module-Neo-6M) shown in Figure 4. Two LiPo (Lithium Polymer) batteries of 4.2 V/2000 mAh each are connected in series to power the circuit. Decoupling capacitors (22 µf -100 µf, 50 V) are used to filter out noise. A 7805 voltage regulator steps down the 8 V Vin to 5 V/1 A. The sim module input voltage is in the range of 3.9 V - 4.3 V therefore a Zener diode (IN4001) is used which has a turn-on voltage of 0.7 V for proper working condition. The decoupling capacitor is to suppress high-frequency noise in power supply signals. They take tiny voltage ripples, which could otherwise be harmful to delicate ICs, out of the voltage supply.

2.5 Altitude and Orbit Monitoring Satellite (DemoSAT- IV)

This DemoSAT- consists of sensors to measure the speed of the satellite using an accelerometer (ADXL335), orientation using a gyroscope (MPU6050) and proximity

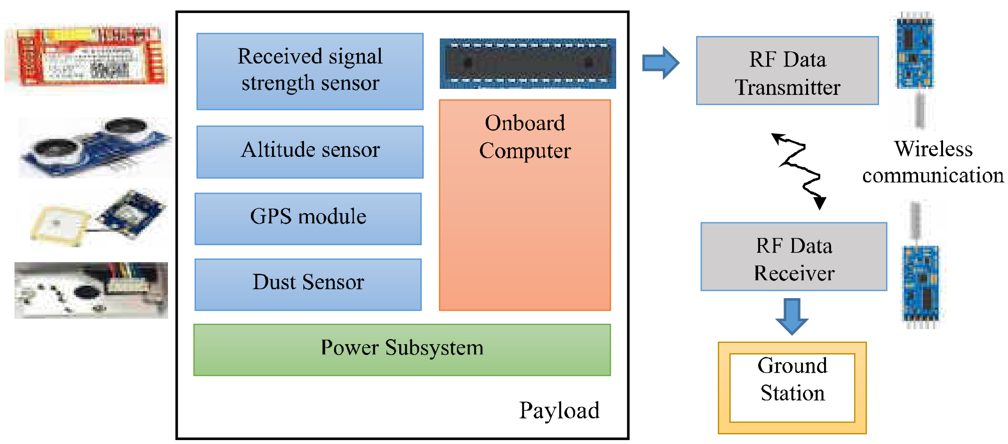

Figure 4: Block diagram of Earth Habitability Monitoring Satellite

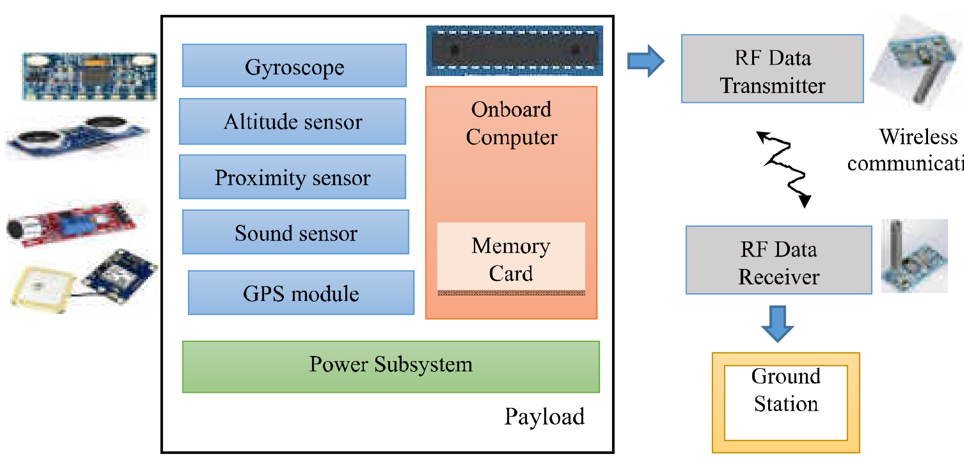

Figure 5: Block diagram of Altitude and Orbit Monitoring Satellite

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(HCSR04) and a sound sensor to detect any objects coming close to the satellite. A GPS Module (Neo-6M) was included for localization and an SD card to save data onboard. HC-12 is also the data transmitter and receiver used for this mission as presented in Figure 5. Two LiPo (Lithium Polymer) batteries of 4.2 V/2000 mAh each were also connected as in DemoSAT- III and are connected in series for the power subsystem.

2.6 Data conversion, Analysis and Presentation Sub-system

COOL TERM, an open-source data collection software, was integrated with the RF signal receiver and data conversion design unit to capture and record converted telemetry data in real-time at the ground station and saved in CSV for further analysis. The aggregated data from the Demo Satellites were separated and converted into CSV using the Python sorting algorithm. This is to distinguish data received from different channels of the ground station and makes the data ready for further analysis and visualization as needed.

A proprietary algorithm was written in python programming language to grab the data in CSV and text format to be converted to JavaScript Object Notation (JSON) and upload the JSON data into a designated database in an automated process. The JSON data using the appropriate sorting algorithm was separated and pass through a secondary business intelligence algorithm to be written in python, JavaScript and MATLAB to convert the data into graphs and visual meters. The data analysis algorithm runs in the webserver and presented via the web dashboard.

2.7 Development of Web Server and Web Dashboard

This is an essential part of processing the telemetry data received to provide meaningful insight and visualization for public use. The Web server was configured using ThingSpeak, an open-source IoT cloud platform from MathWorks with inbuilt functionalities to run MATLAB code, the data were analyzed using a custom algorithm written in python, JavaScript and MATLAB programming languages and a web dashboard was developed (MathWorks, 2020).

Web server, web dashboard and web app were designed using Django framework, python, HTML, CSS, git and javascript to display analysed data in graphs and satellite localization information on maps for users to relate with and deduced informed data-driven decision from the satellite mission. The web server and web app were hosted on a Platform as a Service (PaaS) network for easy accessibility to the Demo Satellite mission both on computer and mobile.

Web dashboard was developed using HTML, CSS, jQuery, JavaScript and bootstrap framework. The dashboard displays the analyzed telemetry data in graphs and meters which allow deduction of meaningful insight from the telemetry data. The dashboard was hosted on the cloud for easy accessibility on personal computers and mobile devices.

2.8 Localization Algorithm

A proprietary algorithm was written to extract latitude and longitude information from stored data. The Self-organizing maps (SOM) algorithm firstly randomizes the map's nodes' vectors (Latitude and Longitude). Then grabs an input vector and traverses each node in the

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map and uses the Euclidean distance formula to find the similarity between the input vector and the map's node's vector, it also tracks the node that produces the smallest distance (this node is the best matching unit, BMU)

The algorithm connects to google map API services for displaying the current location of the Demo Satellites on an actionable google map in real-time. This is essential for position tracking of the Demo Satellite and also adding credibility to the telemetry data received which is location-based. Using REST API and location information gathered by the Demo Satellites, its actual location was visualized on google map.

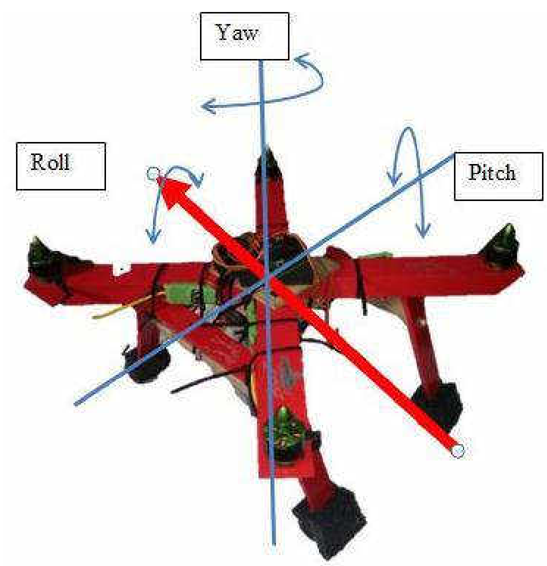

Figure 6: Roll, Pitch and Yaw axes

2.9 Unmanned Aerial Vehicle

Quadcopters (Figure 6) are aerial vehicles with 4 propellers that produce a vertical thrust similar to a helicopter, but unlike a helicopter, no tail rotor is required for stability. The Quadcopter's attitude (aircraft orientation relative to the vehicle's centre of gravity) is completely controlled by four propellers and a control system programmed on a microcontroller. The three axes of rotation on which the aircraft's attitude is defined. Roll, pitch, and yaw are controlled by increasing and decreasing the thrust produced by sets of motors. Figure 7 shows the top view of the Quadcopter along with the rotational direction of the propellers and the associated motor (KK2.1.6 FCB).

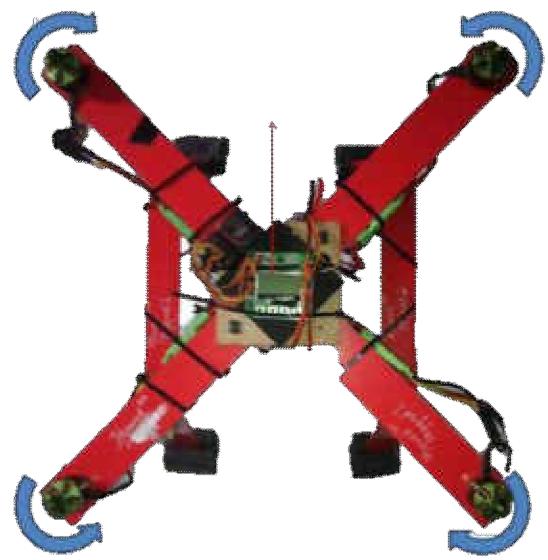

Figure 7: Propeller rotational direction

Quadcopters were developed that will be remotely controlled with the ability to fly for at least 120 seconds carrying a payload of about 300g. To achieve this, a frame which is the major body of this project is designed and fabricated using Pro-Engineer software for drawing and analysis putting into consideration the weight, strength and flexibility of the frame and landing gear that can accommodate shock landing and of lighter weight. MATLAB software is used for few simulations of the Roll, Pitch and Yaw also moment the flight controller and the Electronic Speed Controller in which the codes are written with the aid of Embedded

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MATLAB and convert codes to statically C codes to be embedded in the ATMEG chip of the FCB with the aid of Universal USB Asp cable.

The frame makes up the major body of a quadcopter which includes the axis and body that carries the weight; therefore proper material must be used for the frame design that can withstand bending and torsional stresses. The frame of a quadrotor helicopter has to be rugged while being light enough to take flight. When all of the available materials are taken into consideration, carbon fibre would have been chosen for the frame construction but, it is not available locally. Hence, aluminium proved to be the most effective material for a frame due to its availability, and lightweight. The material chosen for this project is an Aluminum frame (68.9 GPa), the 582-652oC melting point which is a hollow rectangular material with an ultimate tensile strength of about 551 MPa to 560 MPa (AEC, 2010). Aluminium was chosen because of its lightweight corrosion resistance and ease of fabrication.

The final frame design is simple which does not require additional weight from the motor mount. The design of the UAV frame aims to achieve a frame output of 300 grams maximum which is to include the camera holder for video live feed, Demo Satellites and landing skid.

2.10 Other Design Issues (Calibration and Packaging)

Calibration of sensors was carried out by getting another device of known calibration standard which measures the same physical quantity as the sensor in question; measuring the same environmental condition; the maximum and the minimum readings were taken and compared; a mathematical relationship was estimated and considered when writing the program for this setup.

After the integration and testing of the Demo Satellite, errors, results that were not expected were noted and the system was diagnosed. Necessary corrections were made until the desired results were achieved. Packaging also is one of the major factors that affect the marketability of a finished product.

The materials used for packaging of the Demo Satellite are Plastic container: very light in weight and serves as the bus of the satellite. A drilling machine was used to drill circular holes for some sensors, ventilation and smoothening the container. An electric hot glue machine was used to apply hot glue to ensure the firmness of some sensors attached to the body of the satellite. A cutter was also used to make openings and cut out shapes. Arch-saw blade was used in cutting excess plastic materials and a Venier calliper was used to measure dimensions of sensors for accuracy and aesthetics of the DemoSAT-s. Finally, a gas stove to supply heat to the various shapes and sizes of cutters. Figures 8 and 9 shows the Initial packaging and Final packaging of the DemoSAT-1. Figure 10 shows DemoSAT- III, DemoSAT- IV and the Ground Station. While Figure 11 shows a finalized UAV and the UAV ready for a mission with a DemoSAT.

3.0 RESULT AND DISCUSSION

Telemetry data was aggregated from Demo Satellites using COOLTERM (Levine, 2020) and Data aggregated are automatically sorted and converted to an Excel sheet with delimiter

Figure 8: Initial packaging of DemoSAT- I

Figure 9: Final packaging of DemoSAT- I

Figure 10: DemoSAT- III, DemoSAT- IV and the Ground Station

using a custom sorting algorithm written in Python programming Language. Data aggregated from the Demo Satellites were visualized using python and JavaScript in real-time. Web dashboard was developed for public and instant access to the data visualization. The web dashboard contains visual elements that show various parameters measured by the Demo Satellites, the on and off state of the satellite and the data transmission time

The visual elements are shown in Figure 12. The Figure also shows the temperature reading varied with time as transmitted from the DemoSAT-I.

The pressure reading and altitude reading was represented with a meter gauge for easy interpretation on the dashboard as shown in Figure 13. Figure 14 shows the received signal strength in Db using SIM800, a GSM module, as transmitted from DemoSAT-III to the ground station. From the Figure, it was

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observed that signal strength is not constant and varies as the Demo Satellite moves vertically upward. Figure 15 obtained from DemoSAT- IV, shows the bending degree of the satellite and it moves up and the sound experienced by the satellite is oscillatory as shown in the figure. Figure 16 is the inclination angle that correlates to the bending angle of the Demo Satellite. This was measured using the MPU 6050 sensor on DemoSAT-IV. The sensor measures the speed at which the Demo Satellites move. The dashboard indicates that the gyroscope, sound sensor, GPS and accelerometer is ON and fully functional.

4.0 CONCLUSION

There are four Demo Satellites with sensors, transceivers, positioning and data storage devices to simulate satellite data acquisition functions such as environmental monitoring, aerial mapping, localization, satellite diagnostics and cellular network accuracy investigations. Cooperation between ground

Figure 11a and b: A finalized UAV and the UAV ready for a mission with a DemoSAT-

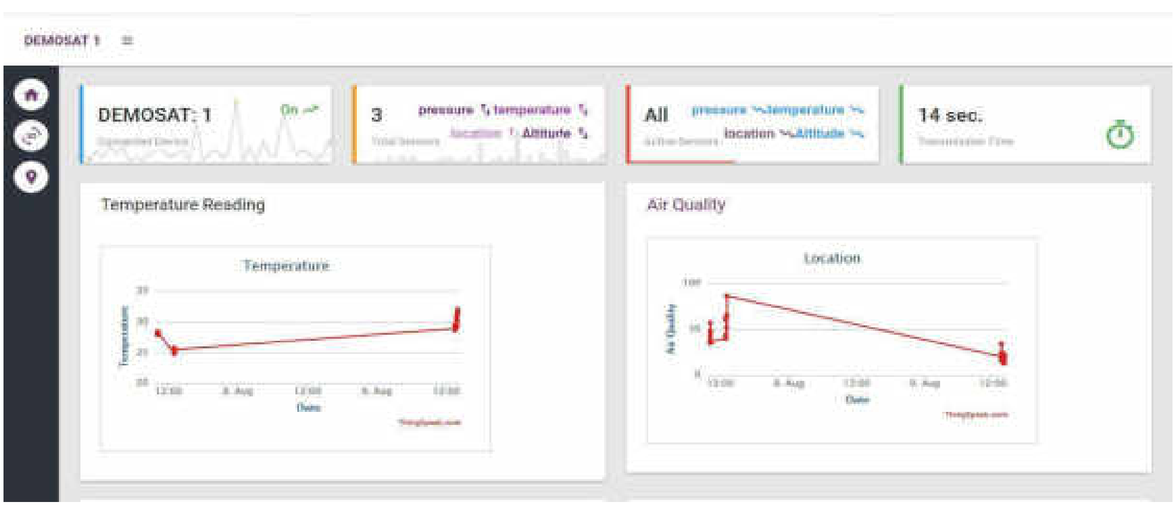

Figure 12: Temperature reading using DHT11 and air quality reading using MQ135.

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Figure 13: Pressure reading using BMP 180 and altitude reading using BMP 180

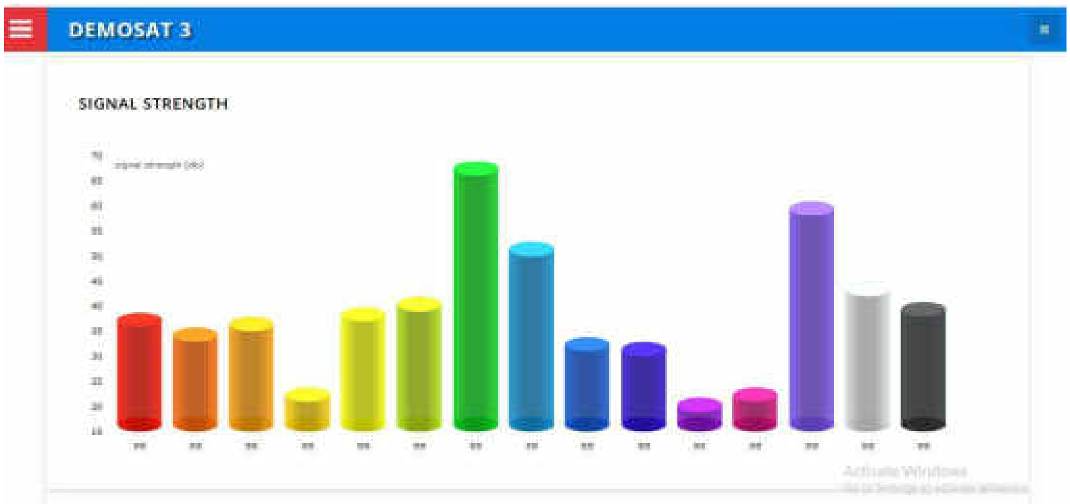

Figure 14: Data visualization of signal strength reading using SIM 800

Figure 15: Data visualization of gyroscope reading using MPU 6050 and sound sensor reading

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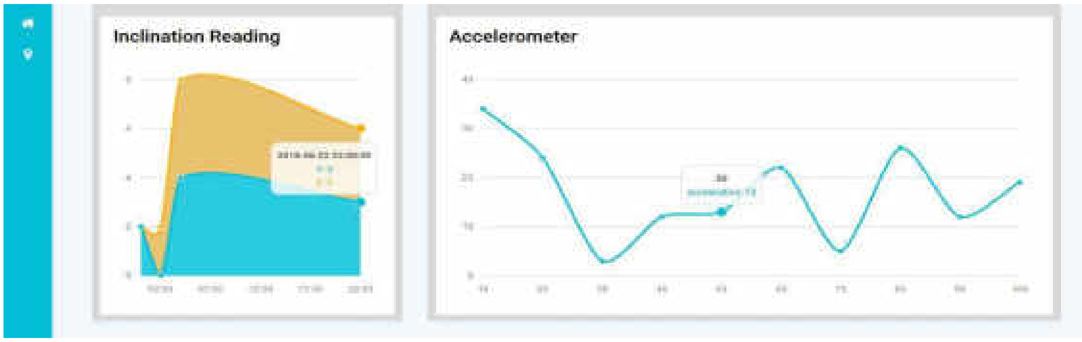

Figure 16: Inclination reading using MPU 6050 and accelerometer reading using MPU 6050

stations provide strong benefits when downloading data from LEO-satellites due to the increase of link-time. However, this is limited by the fact that not only are there multiple ways of transmitting and receiving telemetry data, but also a multitude of ways of implementing a satellite communications protocol. Because of this, it is suggested to implement all ground stations so that they may act in a binary mode. Using this mode, each satellite producer or ground station user can program their specific codes in their program locally. This program then communicates with the satellite through the ground station using, for example, the UDP-protocol across the internet. This work shows that a microcontroller, with some extra components, is capable of performing such a service

At present, the FUTA DemoSATs and DemoSAT's Ground Station developed in this work is fully functional in the amateur radio bands (433 MHz) and an internet of things communication medium. The DemoSATs have unidirectional simplex communication links.

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