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CanSat design and implementation for remote sensing applications

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ABSTRACT

With the increasing potential of satellite technology, it becomes crucial to learn its principles and develop the basic satellite subsystems for the undergraduate level. Working on a real satellite is a challenging target and requires a solid technical background. In contrast, less complex models, such as CanSat, CubSat and HeptaSat, introduce basic ideas to the undergraduate studies level. This paper presents the CanSat design and implementation for remote sensing applications such as measuring the CO_2 level in contaminated areas. The CanSat has the size of a soft drink can and simulates the subsystems of the satellite (e.g., payload, power, communication, onboard computer, and structural). Its mission was to be released from a certain altitude and send real-time data to the ground station during landing. The design process was elucidated at the subsystem level. It included the mission requirements and specifications, component selection, and software and hardware design. Arduino Nano was utilised as an onboard computer. A printed Circuit Board (PCB) was designed using Diptrace© to connect the electronic components to Arduino Nano. Xbee was used as a communication module to send the collected data to the host computer. This data was visualised in real-time by LabView©.

1. INTRODUCTION

The CanSat concept was initially proposed in 1998 by Bob Twiggs, a professor at the University Space Systems Symposium (USSS) [1]. It is a tiny remote satellite with the size and shape of a 350-millilitre soft drink can. It has all the necessary subsystems in a real satellite, such as power, onboard computer, and communication. The purpose of CanSat is to teach university students how to conceptualise the satellite mission and design and fabricate its subsystems [2]. After introducing the initial idea, the CanSat mission has evolved to include more complex aspects. In 2000, GPS was applied to simulate the navigation system [3], and then, in 2001, the concept of

the rover back CanSat was introduced, in which the CanSat has an extra mission after landing on the ground. This mission was to autonomously direct it to a target position [3].

CanSat has recently sparked much interest, particularly among university students and academics since it allows them to design, construct, and build a tiny satellite that can replicate a real satellite with a smaller size and less complicated design [4-6]. CanSat is ideal for academic use since it is less expensive and complex than real big-scale satellites. Numerous international competitions for undergraduate students were held annually to obtain innovative ideas for space technology. These competitions significantly improved the CanSat conceptual design and mission, encouraging more students to understand satellite technology further and skyrocket their technical skills [7].

Obtaining a launch opportunity was proven to be difficult, and the project was switched to a suborbital launch experiment called ARLISS (A Rocket Launch for International Student Satellites) [8], in which CanSats were launched up to 12000 *ft* (3.6 *km*) height using US amateur high-power rockets developed by AEROPAC.

The presented paper aims to demonstrate the design and fabrication of a CanSat prototype that can measure the CO_2 levels, in the atmosphere, at different altitudes. The mission specifications and requirements, subsystem design, systems integration, and fabrication are discussed in detail. The remaining of the paper is presented as follows: Section 2 discusses the mission overview, section 3 explains the design of the subsystem from the hardware perspective, section 4 offers the parachute design procedure, section 5 illustrates the releasing mechanism, section 6 shows the integration of the system, section 7 demonstrates the communication between the CanSat and the ground station. Finally, section 8 concludes the paper.

2. MISSION OVERVIEW

This paper aims to demonstrate the design process of a CanSat that aims to collect environmental measurements (i.e., temperature, humidity, pressure, and CO_2 level) during landing from certain altitudes. In real time, these measurements will be transmitted wirelessly to the ground station and stored in an onboard SD card module for offline analysis.

2.1. Specification and requirements

The designed CanSat system aims to perform and satisfy the following specification and requirements:

- The shape is cylindrical, with a diameter of 6.6 cm and a height of 11.0 *cm*.

- The system's total mass, including the battery, does not exceed 400 *gm*.
- All CanSat operations must be executed autonomously without receiving commands from the ground station.
- The total electric power consumed by the system does not exceed 500 *mW*.

3. CANSAT SUBSYSTEMS

The CanSat consists of four main subsystems: payload, command and data handling, communication, and electrical power subsystems. More details about the design process are discussed in the following subsections:

3.1. Payload subsystem

It consists of stable, reliable, accurate, and fast sensors that were selected very carefully to meet the design requirements. Table 1 shows each sensor used in the CanSat prototype with its functionality and advantages.

3.2 Command and data handling subsystem

The CanSat operation is controlled by an Onboard Computer (OBC) in the Command and Data Handling Subsystem (C&DH). The OBC has software that manages the various tasks performed by the system modules. The architecture of the system's physical components, such as the Microcontroller (i.e., Arduino nano), sensors, and transceiver (i.e., XBee), is connected and managed by the C&DH. Moreover, scheduling the telemetry data received by the sensor and analysing them are also carried out by the C&DH. Table 2 shows more details for the selected Command and Data Handling module.

3.3 Communication subsystem

In a real satellite, the communication subsystem is responsible for transmitting data and receiving commands from the ground station. However, the communication in CanSat in the developed prototype is designed for only one direction (i.e., sending data from the CanSat to the ground station) to satisfy the mission requirement. This requires a wireless communication module to transmit the data within a range of 1 km. Table 3 shows more details about the selected communication module.

3.4. Electrical power subsystem

The Microcontroller and the sensors are powered by three cells, 11.1V and 1350 *mA* Lithium Polymer (LiPo) battery. The Arduino Nano regulates the 11.1*V* battery, stepping it down to 3.3*V* and 5*V* to deliver the needed voltage to each component. The BMP280 and XBee are connected to a 3.3*V* pin, and the MQ-135, Bn-220, and MPU9250 are all connected to the 5 Voltage source.

The ground of each sensor is connected to the ground of the Arduino Nano. The I2C protocol employs two lines—a serial clock pin (SCL) pulsed by the Arduino Controller board at regular intervals and a serial data pin (SDA) used to transmit and receive data. The SCL is connected to analogue pin 5 (A5), and SDA is connected to analogue pin 4 (A4) of Arduino Nano. BMP280 and MPU9250 sensors are using A4 and A5. The electrical schematic for the CanSat is shown in Figure 1.

3.5. PCB design

A printed circuit board (PCB) is a type of circuit board that allows us to install all system components in the physical form [9]. The PCB design process includes components placement and routing them to define electrical connectivity on a printed circuit board using layout software. This work uses Diptrace [10] software to create the PCB. DipTrace is a software suite for creating schematic diagrams and printed circuit board layouts using electrical design automation (EDA).

The following steps are performed to design the PCB:

- The schematic capture is designed.
- All component libraries are brought together, and their elements are linked.
- The schematic is converted into a PCB layout, and then the components are arranged.
- Electronic components are placed on the board, and traces connect them to form a working circuit or assembly.

Table 4 shows the names of the components that are presented in the 3D model. The PCB layout for this system is shown in Figure 2.

Table 1. The selected sensors for the CanSat mission and their functions.

Component	Functionality	Advantages
MQ-135	It measures the contamination of carbon dioxide.	The Arduino board easily configures it with a fast response and long life.
BN-220	It determines the position of the CanSat.	It has a fast transient response and is easily configured by the Arduino board.
MPU-9250	It obtains linear and angular acceleration and the magnetic field.	It has a high performance with low power consumption.
BMP-280	It measures atmospheric pressure, temperature, and altitude.	It has high accuracy and long-term stability.

Table 2. The selected components of the C-and-DH subsystems.

Component	Functionality	Advantages
Arduino Nano	It has a processing unit that handles and analyses the data across the system.	Tiny in size, access to a program, and widely available.

Table 3. The selected components of the communication subsystem.

Component	Functionality	Advantages
XBee	The communication unit transmits data to the ground station.	It has a long transmitting range.
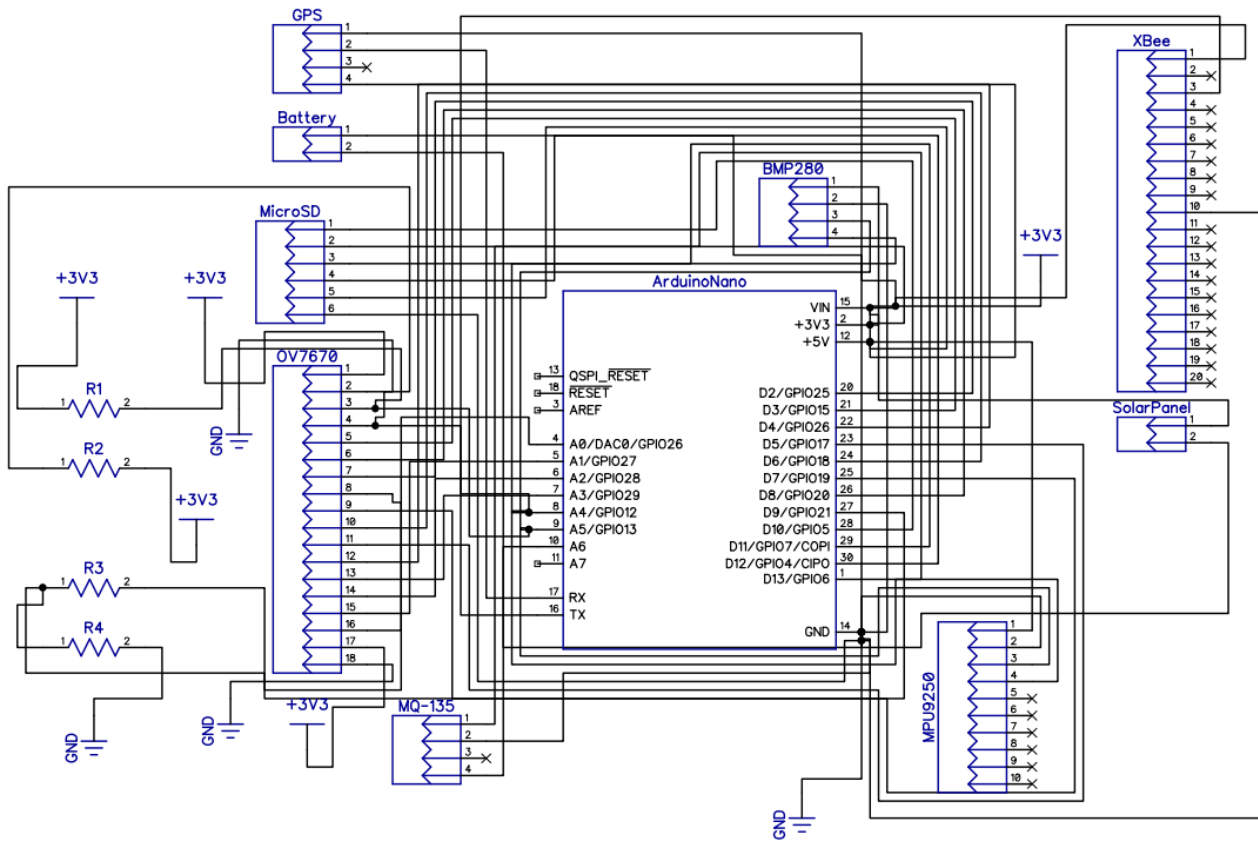
Figure 1. CanSat PCB design schematic capture.

Table 4. List of the CanSat components.

Component	Functionality
1	BN-220
2	XBee PRO 900HP
3	Micro SD Card reader
4	Toshiba MicroSDXC
5	Delta 22 433 MHz
6	MQ-135
7	Arduino Nano
8	Lithium battery drones
9	LD33V
10	L7805
11	MPU9255
12	BME 280
13	OV7670
14	Rubber base
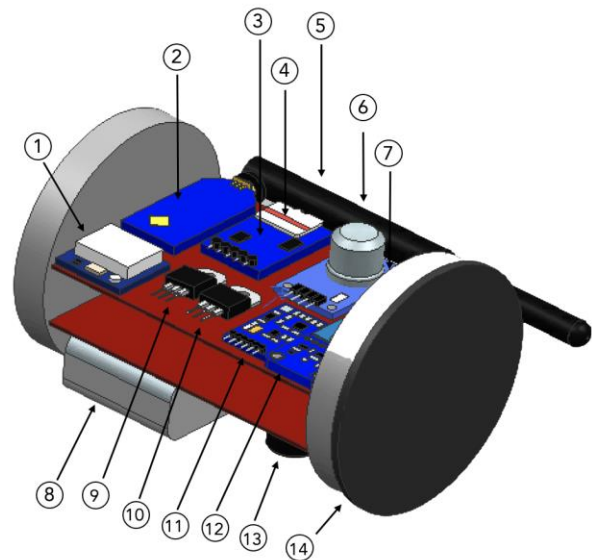
Figure 2. CanSat 3D CAD model with PCB.

3.6. Parachute

The parachute is a vital part of the CanSat mission, and its purpose is to avoid crash land to complete the mission's scientific objectives. A round-shape parachute is selected, and it is made of ripstop nylon and designed with a diameter of 80 cm. The parachute is tested from the 5th

floor, about 15 meters in height, with an average descending speed of 1.87m/s. Figures 3 and 4 show the final design and the parachute test, respectively. Equations (1) and (2) discuss the descending speed that should be considered in the design process based on the design procedure presented in [11] and [12].

$$D = \frac{1}{2}C_d\rho v^2 A = mg \tag{1}$$

$$v = \sqrt{\frac{2mg}{\rho C_d A}} \tag{2}$$

where D, m, g, ρ, C_d, and A are the drag force, the mass of the CanSat, the gravitational acceleration, the air density, the aerodynamic drag coefficient, and the surface area of the parachute, respectively.

Figure 3. The final design of the parachute.

Figure 4. Testing 80 cm diameter parachute.

3.7. Releasing mechanism and CanSat box

The box's purpose is to carry the CanSat, including the parachute. It will be attached to a drone at a certain altitude, and then the box doors will be opened using a releasing mechanism to let the CanSat fall smoothly and start its mission. The releasing mechanism consists of a tiny box that includes an Arduino nano, servo motor, on-off switch, tactile switch, RGB led bulb, PCB board, battery, potentiometer, and a lock driven by a servomotor (see Figures 5 and 6). Once the switch is turned on, the RGB led bulb will turn on, the lock that is driven by a servomotor will automatically open, and the tactile will control the opening of the box's door by opening the lock and closing it. The duration of time is adjusted to open the box's doors by setting the potentiometer, each step of the potentiometer represents one minute, and the maximum range is 10 minutes. After the time is adjusted, the tactile switch is clicked, and the lock controls the closing of the doors. Once the duration finishes, the lock will open, and the doors will open to let the CanSat fall.
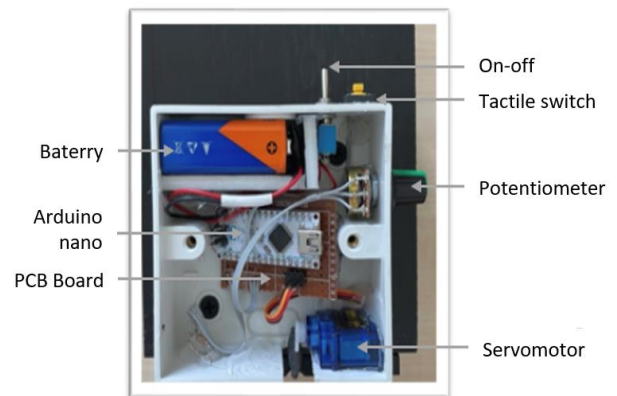

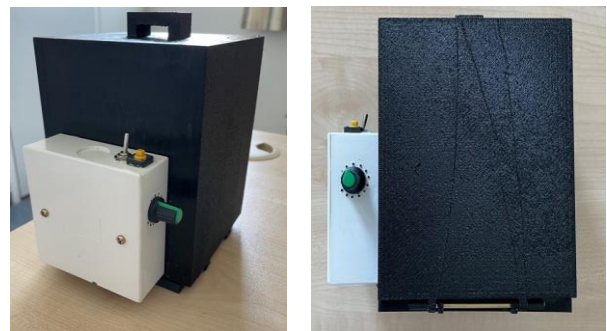Figure 5. Releasing mechanism tiny box components.

Figure 6. Final box design with the releasing mechanism.

4. SOFTWARE DESIGN AND REALISATION

4.1. Integration and test

Subsystem testing (see Figure 7) is carried out at this stage since the project is built of numerous components that work together to achieve the major tasks. This subsystem testing helps to check the behaviour of each element. After finalising the design and integrating the system (see Figures 8 and 9), the following specification is achieved:

- The shape is cylindrical, with a diameter of 6.6 *cm* and a height of 11.0 *cm*.
- The total mass is 374 *gm*.
- The total electric power consumed by the system is 400 *mW*.
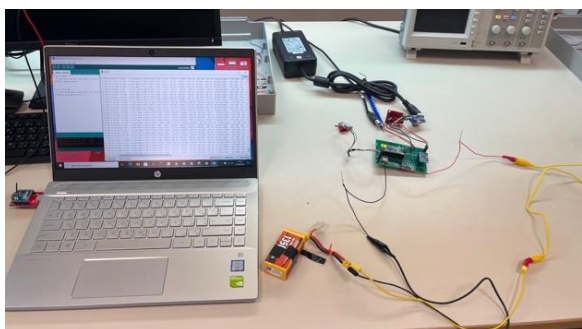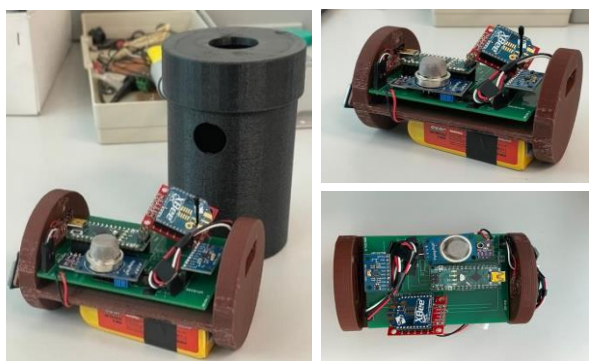

Figure 7. Testing the sensors.

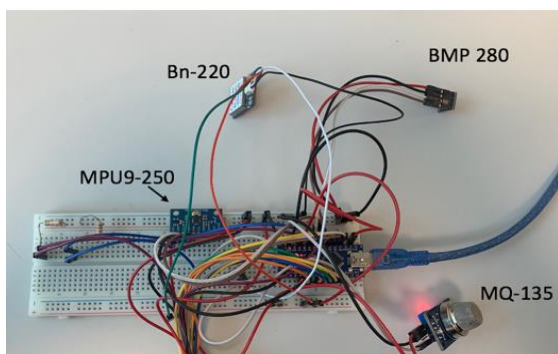**Figure 8. Integration of CanSat subsystems.**

Figure 9. The circuit of the sensors on a breadboard.

4.2. Interfacing check

Arduino Integrated Development (IDE) [13] is the software for coding/uploading the codes to the Arduino board. Moreover, it is used to Read the data from the sensors via serial monitor to check whether the code is correct and the sensors are working correctly.

5. GROUND STATION DESIGN

Mainly, the ground station consists of workstations and receivers to collect the transmitted data from the CanSat. When the CanSat is launched, the ground station will receive all the data needed for the scientific experiment via radio waves with a specific frequency [14]. The communication setup contains three main components computer, a transceiver attached to an antenna, and a receiver. A transceiver (XBee S2C), as shown in Figure 10, is a wireless communication or data exchange RF module that uses ZigBee mesh communication protocols on top of the IEEE 802.15.4 PHY. The module allows wireless access to ZigBee mesh network end-point devices.

Figure 10. Transceiver (XBee).

5.1 Ground station graphical user interface

The main objective of the ground station is to receive and display the time variation of the collected data in real-time. During the CanSat descending phase, the communication module (i.e., Xbee) sends the collected data to the ground station that receives those data through another communication module. Then, LabView [15] software is utilised for visualising the data in clear form.

The data from the ground station are temperature, and pressure, Air quality measurement for CO_2 and IMU, and GPS with a map for the location. Figure 11 depicts the Graphical User Interface (GUI) of the collected data.
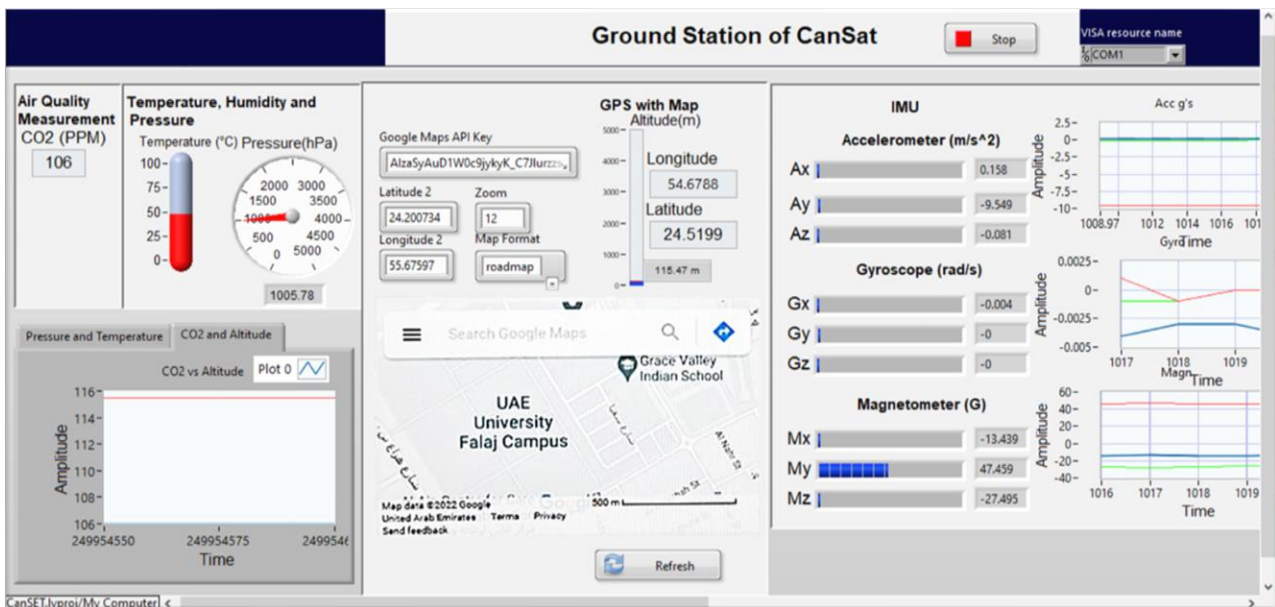
Figure 11. Ground station display window.

6. CONCLUSION

The paper presents a detailed design for a CanSat system that can be released from a certain altitude. When the release mechanism stage began, the parachute unfolded from the CanSat storage box compartment to ensure reliable separation and a safe landing. A 3D printing machine fabricated the CanSat structure and its box. Arduino Nano microcontroller was employed, and extensive engineering and testing of all electronics were performed before the final layout circuit connection of I/O pins and interfaces in Diptrace©. Ground station software was developed using LabView© to visualise real-time data from sensors (temperature, pressure, IMU data, and CO_2 level) and GPS trajectory data. In summary, the CanSat was tested successfully, and all sensor telemetry data were collected and transmitted wirelessly during the landing phase, using Xbee modems to a host computer for real-time visualisation.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interest affecting this publication.

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