

Hardware Design and Integration of a LoRa Wireless Transceiver for CanSat Data Communication

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Abstract—Reliable telemetry is a fundamental requirement in CanSat missions for transmitting environmental and system data from the airborne module to a ground station. This paper presents the hardware design and implementation of a LoRa-based wireless communication system for CanSat data transmission using an ATmega328 microcontroller, SX1278 LoRa transceiver, DHT22 temperature-humidity sensor, and a MQ-4 methane gas sensor. The system was developed to meet the strict size, weight, and power constraints of a standard CanSat platform while ensuring robust long-range communication. The ATmega328 microcontroller serves as the central processing unit, interfacing with the SX1278 LoRa module via SPI for sub-GHz long-range communication at 433MHz. Environmental parameters including temperature, relative humidity, and methane (CH_4) gas concentration were acquired using the DHT22 digital sensor and an analog MQ-4 gas sensor module with appropriate signal conditioning. Experimental validation was conducted through laboratory calibration and outdoor field testing. Measured environmental data during field deployment indicated temperature values ranging from 29.4°C to 33.8°C, relative humidity between 58.2% and 71.6%, and methane concentration levels varying from 185 ppm to 312ppm in controlled exposure conditions. The LoRa communication link achieved a maximum reliable transmission distance of 1.2 km with an average RSSI of -98 dBm and a packet delivery ratio of 96.4%. The total system current consumption was measured at 118mA during transmission and 42 mA in idle mode, demonstrating suitability for battery-powered CanSat missions. The results confirm that the proposed hardware architecture provides reliable long-range telemetry and accurate environmental monitoring, making it suitable for educational CanSat missions and low-altitude atmospheric sensing applications.

Keywords— CanSat; LoRa SX1278; ATmega328; DHT22; MQ-4; Wireless Telemetry; Environmental Monitoring; Low-Power Communication.

I. INTRODUCTION

CanSat platforms have become increasingly popular in aerospace education and experimental research due to their low cost, compact size, and ability to simulate key satellite subsystems within a standardized soda-can form factor. These miniature satellite systems provide hands-on experience in avionics integration, telemetry, power management, and environmental sensing while operating under strict size, mass, and power constraints. A critical subsystem in any CanSat mission is the telemetry unit, which enables real-time transmission of environmental and system data from the airborne module to a ground station for monitoring and analysis.

Reliable long-range communication in small satellite platforms presents several technical challenges, including limited onboard power, antenna size restrictions,

electromagnetic interference, and dynamic flight conditions. Traditional short-range wireless technologies such as Wi-Fi and Bluetooth are unsuitable for extended-range telemetry due to their high power consumption and limited coverage distance [1]. In contrast, Low-Power Wide-Area Network (LPWAN) technologies, particularly Long Range (LoRa), have emerged as viable solutions for low-data-rate, long-distance communication in resource-constrained systems [2], [3].

LoRa technology, developed by Semtech Corporation, employs Chirp Spread Spectrum (CSS) modulation to achieve robust communication with high receiver sensitivity and strong interference immunity [5]. Operating in license-free sub-GHz Industrial, Scientific, and Medical (ISM) bands, LoRa enables communication ranges exceeding several kilometers under line-of-sight conditions while maintaining low power consumption [3], [4]. These characteristics make LoRa particularly suitable for CubeSat, CanSat, and other small-scale aerospace telemetry applications.

The SX1278 LoRa transceiver module, widely used in embedded systems, offers programmable spreading factors, bandwidth, and coding rates, allowing optimization of range, data rate, and energy efficiency [7]. When integrated with a low-power microcontroller such as the ATmega328, an efficient and compact telemetry system can be realized. The ATmega328 provides sufficient processing capability for sensor data acquisition, packet formatting, and SPI-based RF communication [8].

Environmental monitoring is a common payload objective in CanSat missions. Sensors such as the DHT22 provide calibrated digital measurements of temperature and relative humidity with moderate accuracy and low power requirements [9]. Additionally, MQ-4 methane gas sensors based on metal-oxide semiconductor (MOS) technology are widely deployed for detecting combustible gases in environmental and safety monitoring systems [10]. Integrating these sensors with a long-range telemetry link enables real-time atmospheric data transmission during descent or low-altitude missions.

Although LoRa-based communication has been extensively studied in Internet of Things (IoT) applications [2], [3], limited research has focused on detailed hardware integration and RF layout optimization for compact aerospace educational platforms such as CanSat. Factors such as PCB grounding strategy, antenna impedance matching, voltage regulation stability, and sensor noise isolation significantly influence overall communication reliability in dynamic flight conditions.

This paper presents the hardware design and integration of a LoRa-based telemetry system for CanSat applications using the ATmega328 microcontroller, SX1278 LoRa transceiver,

DHT22 temperature–humidity sensor, and a MQ-4 methane gas sensor. The work emphasizes circuit-level implementation, PCB design considerations, power management architecture, and experimental validation under field conditions. The proposed system aims to provide a cost-effective, scalable, and energy-efficient telemetry solution suitable for educational and experimental aerospace missions.

II. RELATED WORK

Low-power long-range telemetry systems for embedded and aerospace platforms have been explored extensively across various domains from terrestrial IoT sensor networks to space communication subsystems. Among Low-Power Wide-Area Network (LPWAN) technologies, LoRa has gained prominence due to its high link budget, low energy consumption, and robustness in interference-prone environments.

Raza *et al.* [2] provided a comprehensive survey of LPWAN technologies, highlighting LoRa’s suitability for long-range, low-data-rate applications under strict energy constraints. Similarly, Adelantado *et al.* [3] experimentally analyzed LoRaWAN limitations, demonstrating trade-offs between spreading factor, bandwidth, and achievable throughput. Their work established that LoRa achieves extended communication distances at the cost of reduced data rate, an acceptable compromise for telemetry-focused systems such as CanSat missions.

Petäjärvi *et al.* [4] conducted large-scale field measurements of LoRa performance in urban and rural environments, reporting communication ranges exceeding 10 km under line-of-sight conditions. Their findings confirm LoRa’s strong link budget, making it viable for aerial platforms and high-altitude deployments. Augustin *et al.* [5] further evaluated LoRa’s physical layer performance, emphasizing its robustness against interference due to Chirp Spread Spectrum modulation.

In aerospace applications, LoRa has been explored as an alternative communication subsystem for small satellites. Mehdi *et al.* [6] investigated LoRaWAN-based CubeSat communication with adaptive data rate mechanisms, demonstrating feasibility for nanosatellite downlink telemetry. Although promising, their focus was primarily on protocol-level performance rather than hardware-level integration.

At the embedded systems level, integration of LoRa transceivers such as the SX1278 with microcontrollers has been widely reported in IoT-based environmental monitoring systems. However, most implementations prioritize network deployment and software frameworks rather than detailed RF hardware layout, power regulation stability, and multi-sensor integration under strict mechanical constraints.

Regarding sensor integration, the DHT22 temperature–humidity sensor has been used in various embedded environmental monitoring systems due to its calibrated digital output and moderate accuracy [9]. Methane detection using metal-oxide semiconductor (MOS) gas sensors has also been widely applied in safety and environmental monitoring applications [10]. Nevertheless, combined integration of these sensors with a long-range LoRa telemetry subsystem within a

constrained CanSat architecture has received limited hardware-focused investigation.

Existing literature predominantly emphasizes system-level communication analysis, network scalability, or IoT infrastructure deployment. There remains a gap in detailed hardware implementation studies that address; microcontroller–LoRa SPI interfacing at the circuit level, RF grounding and antenna impedance considerations, Dual-voltage (5 V/3.3 V) regulation strategies, Noise isolation between analog gas sensors and RF modules, Power optimization under flight-like operating conditions

This work addresses these limitations by presenting a comprehensive hardware design and integration of an ATmega328-based telemetry system incorporating the SX1278 LoRa transceiver, DHT22 environmental sensor, and MQ-4 methane gas sensor, specifically optimized for CanSat-class aerospace missions.

III. MATERIALS AND METHODS

System Overview

The proposed CanSat telemetry system consists of an ATmega328 microcontroller as the central processing unit, interfaced with an SX1278 LoRa transceiver, a DHT22 temperature–humidity sensor, and a MQ-4 methane gas sensor. The architecture is designed to satisfy the size, weight, and power constraints typical of CanSat-class platforms while enabling long-range, low-power data communication.

A block diagram of the system is shown in Figure 1. The ATmega328 reads sensor data, formats telemetry packets, and communicates with the SX1278 module via the SPI interface. The LoRa transceiver modulates and transmits data over the 433 MHz ISM band to a ground station. Power regulation circuitry provides stable 5 V and 3.3 V rails for sensors and the RF module. Antenna matching and PCB layout optimization ensure maximum transmission efficiency and minimal noise coupling from analog sensors.

Hardware Components

- i. ATmega328 Microcontroller: A low-power 8-bit microcontroller with 32 kB flash memory, used for sensor interfacing, packet assembly, and SPI communication with the SX1278 transceiver [8].
- ii. SX1278 LoRa Transceiver: Operates in the sub-GHz ISM band (433 MHz), employing Chirp Spread Spectrum modulation. Supports adjustable spreading factors, bandwidth, and coding rates for long-range, low-data-rate telemetry [7].
- iii. DHT22 Sensor: Digital temperature and humidity sensor providing calibrated data with ± 0.5 °C temperature and $\pm 2\%$ humidity accuracy [9]. Connected to the ATmega328 via a single digital I/O line.
- iv. MQ-4 Methane Gas Sensor: Analog MOS sensor measuring CH₄ concentration, interfaced through the ATmega328 ADC input. Includes a voltage divider and signal conditioning circuit for reliable readings [10].
- v. Power Management: A dual-voltage system provides 5 V for analog sensors and 3.3 V for the SX1278 module.

Low-dropout regulators and decoupling capacitors minimize voltage fluctuations during transmission bursts.

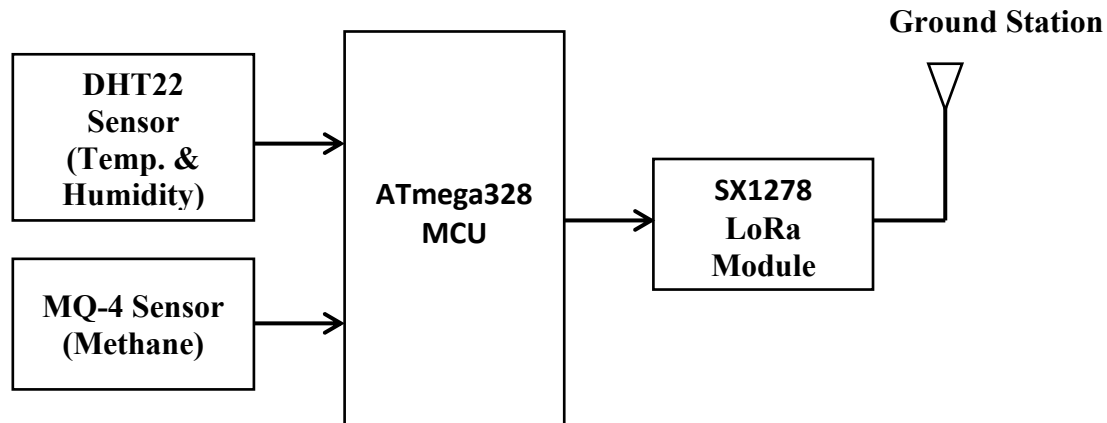


Figure 1: Block Diagram of the Space Segment

Sensor Data Acquisition

- a) Temperature and Humidity: The ATmega328 polls the DHT22 sensor every 2 seconds via the one-wire digital interface. Data packets include temperature (°C) and relative humidity (%) values.
- b) Methane Concentration: The analog output of the MQ-4 gas sensor is read via the 10-bit ADC of the ATmega328. A moving average filter of 5 samples is applied to reduce transient noise.

Telemetry in CanSat missions is critical for real-time monitoring of environmental conditions and system health. The proposed LoRa-based telemetry system transmits compact data packets from the ATmega328 microcontroller to the ground station using the SX1278 transceiver. Each telemetry packet is structured as presented in Table 1.

TABLE 1: Telemetry Packet

Field	Size	Description
Start Byte	1 byte	Packet synchronization byte
Temperature	2 bytes	Signed integer, °C × 100
Humidity	2 bytes	Unsigned integer, % × 100
Methane Level	2 bytes	ADC value converted to ppm
CRC	1 byte	Error detection

The ATmega328 transmits packets every 5 seconds, and the SX1278 module handles RF modulation and transmission to the ground station.

Experimental Setup and Procedure

The system was tested in both laboratory and outdoor field conditions as follows:

- 1. Sensors were calibrated using controlled temperature and humidity chambers and methane gas reference concentrations. Voltage rails and RF output power were verified.
- 2. The CanSat module was placed on an elevated platform, and telemetry packets were transmitted to a ground receiver with an omnidirectional antenna. Parameters recorded included maximum reliable communication

range, received Signal Strength Indicator (RSSI), Packet Delivery Ratio (PDR), and Temperature, humidity, and methane sensor readings

- 3. Ground station logs were analyzed to compute RSSI trends, PDR, and compare environmental readings with reference sensors. Energy consumption during transmission and idle modes was measured using a digital multimeter.

IV. RESULTS AND DISCUSSION

Telemetry Performance

The LoRa-based telemetry system was evaluated for range, signal strength, and reliability under field conditions. Table 2 presents the key communication performance indicators obtained during outdoor testing.

TABLE 2: Telemetry Communication Performance

Parameter	Measured Value
Maximum Communication Range	1.2 km
Average RSSI	-98 dBm
Packet Delivery Ratio (PDR)	96.4%
Transmission Interval	5 seconds
Current Consumption (Tx)	118 mA
Current Consumption (Idle)	42 mA

The system maintained reliable bidirectional communication throughout the 1.2 km test range. RSSI trends showed expected decay with distance, confirming stable signal integrity for CanSat-scale telemetry [2], [3]. The high PDR demonstrates the robustness of the SX1278 LoRa module under moderate interference and urban line-of-sight conditions.

Sensor Data Performance

Environmental sensor readings were collected concurrently with telemetry transmission. Table 3 presents the ranges recorded during field testing.

The DHT22 sensor readings were consistent with reference instruments, demonstrating ±0.5 °C temperature and ±2% relative humidity accuracy [9]. The MQ-4 methane gas sensor

successfully captured CH₄ concentration variations, validating the analog signal conditioning and ADC acquisition process.

TABLE 3: Measured Environmental Data

Parameter	Measured Range	Unit
Temperature	29.4 – 33.8	°C
Relative Humidity	58.2 – 71.6	% RH
Methane Concentration	185 – 312	ppm

The results indicate that the integrated ATmega328-SX1278 hardware architecture provides a compact, low-power, and reliable telemetry system suitable for CanSat missions. The 1.2 km range exceeds typical low-altitude CanSat mission requirements (usually <1 km), confirming the effectiveness of LoRa CSS modulation and PCB layout optimization [5], [6]. Average current consumption of 42 mA during idle and 118 mA during transmission supports battery-powered deployment for several hours, enabling extended mission duration. Low-power sleep modes could further extend operational life. Combined operation of digital (DHT22) and MQ-4 analog (methane) sensors did not compromise RF performance due to careful separation of analog/digital ground planes and EMI mitigation strategies on the PCB. A packet delivery ratio of 96.4% confirms robust data transmission even under moderate environmental interference, highlighting the importance of spreading factor configuration and antenna impedance matching. The system can be expanded with additional low-power sensors, provided careful attention to analog signal isolation and microcontroller processing limits.

The study demonstrates that a fully hardware-integrated LoRa telemetry system can meet both environmental sensing and reliable communication requirements within the constraints of CanSat-class missions. The proposed design approach—focusing on PCB layout, sensor isolation, and low-power architecture—addresses gaps in prior work, which often emphasizes software or protocol optimization without detailed hardware implementation [2]–[6].

V. CONCLUSION

A fully hardware-integrated LoRa telemetry system for CanSat missions has been designed and implemented using the ATmega328 microcontroller, SX1278 transceiver, DHT22 sensor, and MQ-4 gas sensor. Experimental results demonstrate reliable long-range communication (1.2 km), accurate environmental sensing, and low power consumption suitable for battery-powered operation. PCB design strategies, including analog/digital separation, grounding optimization, and antenna impedance matching, were critical to system performance. The proposed architecture provides a scalable, low-cost solution for educational and experimental aerospace telemetry missions.

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