The development of the atmospheric monitoring system for a balloon-borne system

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Abstract. Atmospheric monitoring systems are essential for monitoring weather conditions and assessing air quality, which is critical for public health as well as climate research. While ground-based monitoring systems offer localized data, there remains a gap in measurements at higher altitudes of the atmosphere. The use of balloon-borne systems helps us monitor atmospheric conditions at high altitudes in real-time, which is essential for understanding global climate patterns, air quality, and enhancing our knowledge of upper atmospheric phenomena. In this work, the atmospheric monitoring system for a balloon-borne system is proposed, aiming to overcome the limitations of ground-based monitoring systems (Automatic Weather Stations) by providing a cost-effective method for atmospheric data collection at different altitudes. Over the atmospheric conditions, the system is designed to monitor the position and velocity of unmanned vehicles such as rockets or drones. The components used are not on the military standard, the sensors, the GPS(Global Positioning System) for the system position in the atmosphere, and the radio transmitter for real-time data transmission. The collected data is transmitted to the nearest ground base, which, through the GSM(Global System for Mobile), can transmit the data globally..

1. Introduction

The development of balloon-borne systems began long ago as airborne transportation evolved from kites to unmanned balloons and weather balloons for weather monitoring [1]. One of the earliest valuable uses of balloons for scientific purposes was demonstrated in the early 20$^{\text{th}}$ century, when the tropopause was discovered. Over time, balloon-borne systems have found applications in academia and civilian sectors to support aviation. When developing such systems, it is important to consider the environment in which they operate in. Since some sensors, like those for humidity and temperature, need to be directly exposed to the ambient air, finding suitable sensors that can maintain operation becomes essential, especially since temperatures in the troposphere can drop to about -55 °C depending on the region and season [2].

The design of this balloon-borne system features a Positive Temperature Coefficient (PTC) thermistor for temperature sensing, which is a thermally sensitive semiconductor resistor that changes its resistance as the temperature changes [3]. The PTC increases its resistance with an increase in temperature, and they are made of doped polycrystalline ceramic based on barium titanate [3].

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2. System Boards

The developed balloon-borne system consists of two boards, with the first being the main board, which serves as the system's core. This board includes the Microcontroller (MCU) ATmega328P, known for its use in Arduino boards. The MCU controls the entire system. The main board also features the GPS Neo-6m, providing positioning information such as time, latitude, longitude, and altitude. The board is provided with an onboard transmitter to send the collected data to the ground station. Data is transmitted in binary format because for long distance the bit rate is low, and it is not possible to transmit the numerical values in the form of characters.
The MCU used has limited storage, necessitating working around this limitation. So, binary transmission is advantageous in handling large amounts for data efficiency. Additionally, the board includes a power monitor to track battery life. Monitoring the power helps take measures before the system completely shuts down. The electronic schematic of the main board is shown in Figure 1.

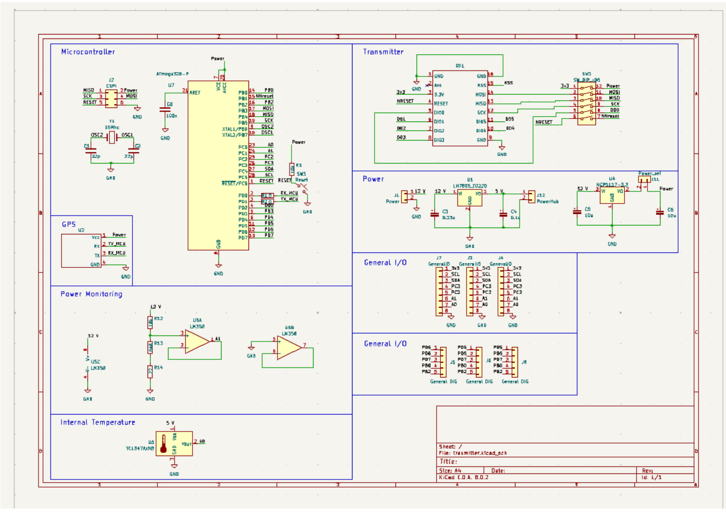

Figure 1. The schematic of the main board.

The second board is the sensor board, which contains the signal conditioning circuit for the sensor signals that are exposed to the environment. The circuit of the sensor board is represented in Figure 2.

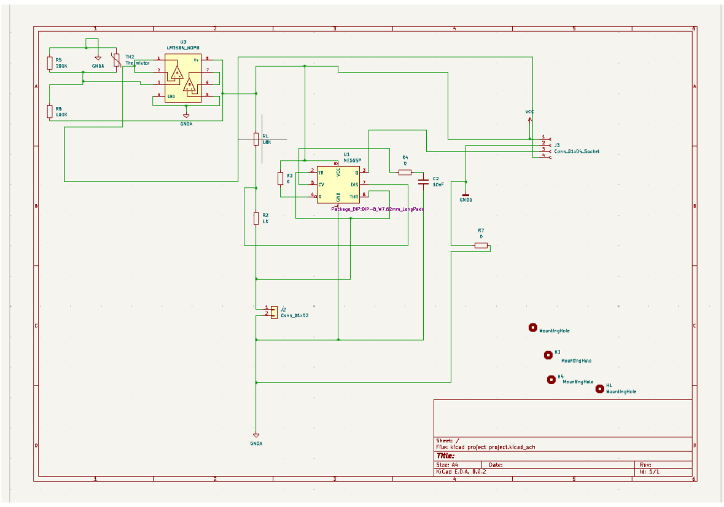

Figure 2. The schematic of the sensor board

The sensors chosen were based on:

- Weight, because to be in line with the actual safety regulation, the payload must not be above 2kg.
- Operation temperature range.
- Efficiency.
- Cost-effective.

The Printed Circuit Board (PCB) of the sensor board was produced in-house, and the main board was then sent for fabrication. To make the PCB, we used the toner transfer method. The first step was to print the PCB design on the blue press and peel sheet, and melt it on top of the copper-clad board using a hot iron. After transferring the PCB design to the copper board, rectification was done through a permanent marker. Placed the PCB in ferric chloride to etch, heating the unwanted copper, leaving only the copper traces. Using available digital/analog pins of the MCU on the main board, the sensor board can be connected. Since the payload must be within the regulated weight, one of the most critical parts that characterizes the weight and the period of the mission is the power subsystem. The main board includes several parts. The power subsystem is made of two voltage regulators that reduce the 12V power supply to work as two independent power sources. One power source is used to power the MCU on the main board and any other service that runs at 5V. The second power source is dedicated to the transmitter and sensors, which operate with 3.3V.

3. System Operation

The system architecture, illustrated in Figure 1, consists of a GPS module that communicates with the microcontroller unit via a USART interface, enabling serial data transmission. A LoRa transmitter is connected to the MCU, utilizing the SPI protocol. The main board's design is flexible, with MCU ports and pins arranged in a parallel setup that makes it easier to add extra sensors without requiring a new design. Furthermore, power monitoring is achieved through a voltage divider that splits the voltage from 0V to 5V. Additionally, an onboard temperature sensor provides real-time analog temperature readings, thereby enabling continuous monitoring of the system's internal temperature.

3.1. LoRa Transmitter
LoRa is a wireless radio frequency (RF) communication technology developed by Semtech, offering a significantly greater communication range and lower power consumption compared to traditional technologies like Wi-Fi and Bluetooth. While LoRa supports bidirectional communication, it operates in half-duplex mode, allowing for either transmission or reception, but not simultaneously [4]. LoRa transmitters operate by converting digital data into chirped RF waveforms using chirp pulses, through a specialized modulation scheme called Chirp Spread Spectrum (CSS) [5], which was initially developed for radar use in the 1940s [6]. These signals are radiated through an antenna.

4. System Software and Testing
At the ground station, we have developed a software that receives the atmospheric parameters, as well as the geographical coordinates, as a series of 23 bytes, which are read byte by byte and reconstructed into usable information. Once the 23 bytes are correctly received, the software at the ground station can calculate the 3D velocity of the balloon and monitor the internal status of the payload and the service systems. The balloon-borne system that is developed does not do calculations; calculations are done on the ground station. The system only transmits the data; this works around the storage limitations of the MCU. The system software test was conducted utilizing a Neo-6M GPS module, extracting time, latitude, longitude, and altitude data. Atmospheric parameters were simulated using International Telecommunication Union (ITU) models, and the system battery voltage was reduced by 0.01V to mimic real-world balloon system data collection conditions. The data was successfully transmitted to and read by the software developed. For this test, a Mega2560 microcontroller unit was used due to its simultaneous transmission and reception capabilities, unlike the ATmega328p MCU. This approach allowed for thorough validation of the software functionality before assembling the transmitter and the receiver. Notably, the GPS module required at least 4 minutes to determine its precise location during a cold start.

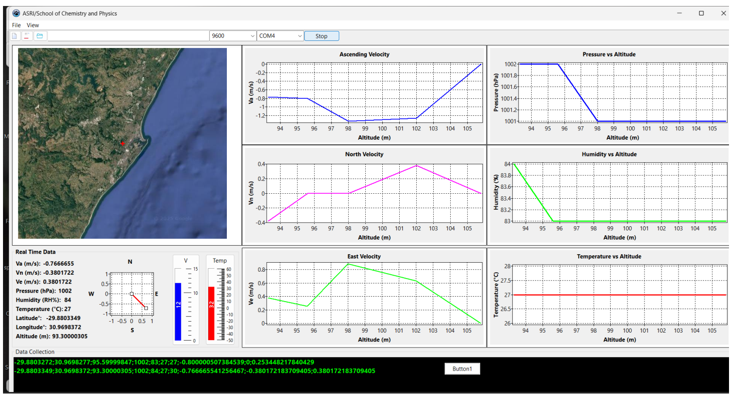

Figure 3. The software showing simulated data.

5. Experimental testing of the sensor board
5.1. Simulation
The circuit design shown in Figure 4 below worked, but it is not the ideal circuit for our system. The circuit in Figure 4 is intended for temperature sensors that reduce their resistance as the temperature increases.

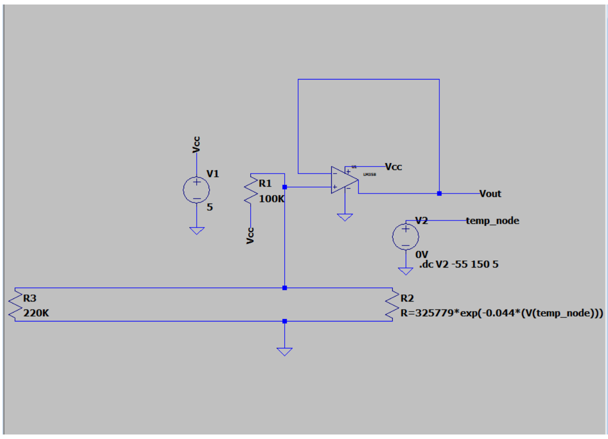

Figure 4. The temperature sensor circuit design.

The PTC thermistor used to measure the temperature is not calibrated. To calibrate the PTC thermistor, a hot air station was used for different high temperature ranges. For lower temperatures, an ice cube with salt was used. The salt was used to lower the ice's freezing point. The thermocouple voltage produced for each temperature was measured with a multimeter. Then, the calculation of the voltage at -40 °C was performed using the equation of the line of best fit. Since the microcontroller that is being used has a 10-bit ADC, different reference voltages were taken to determine the minimum and maximum temperatures measurable for each reference voltage. The ideal reference voltage should provide a small resolution for accurate temperature measurement. An HS4103 can replace a PTC thermistor since it can accurately measure both relative humidity and temperature. It uses a Micro Electro Mechanical Systems (MEMS) sensor to detect changes in humidity and temperature in its environment [7]. The sensor is factory-calibrated, so no user calibration is required.

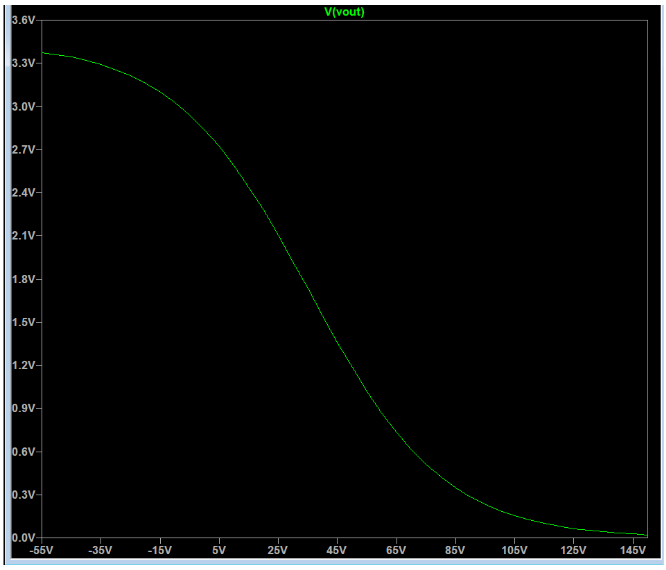

Figure 5. The simulation plot.

The x-axis on the plot shown in Figure 5 represents the temperature change. Each voltage value in the y-axis corresponds to the simulated temperature points on the x-axis. Using a PTC thermistor on this existing circuit design is not ideal since the voltage output becomes constant at higher temperatures, making it difficult to determine the exact temperature from the output voltage. A new circuit design is therefore required.

6. Sumarry

The packet size of 23 bytes is suitable for achieving better performance when using a LoRa system. From a steady location and with simulated parameters, the ground station and the balloon system seemed to communicate correctly. The system can be configured with other sensors to use at high altitudes. The sensor board can be reconfigured to the researcher's needs, as it can be produced separately from the main board. The future work will improve the PTC thermistor circuit for high-altitude performance.

7. Acknowledgement

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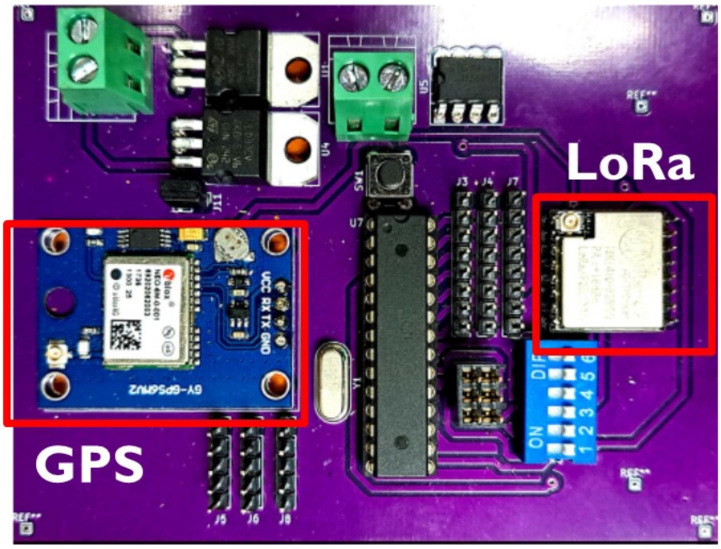

Figure 6. The main board.

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