A Model of Cube-Sat

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ABSTRACT

Weather satellite is a type of satellite which is mainly used for the monitoring of the weather and climate of the Earth. This project purposes the creation of a working model of weather cube-sat, a weather Pico-satellite to monitor the condition of a small geographical area and determine its weather conditions and pollution level. Various sensors like temperature, barometric, humidity, dust and lux intensity sensors as well as a rain detector is used to measure the corresponding physical quantities and situations for this purpose. This system uses nRF transceivers for the transmission of data from the cube-sat to the ground station. Even though it is not included in our project, it is also possible to forecast the weather for the area based on previous values measured from the system. For the validation of the project, the measured data were compared with each other as well as the corresponding values of the physical quantities measured from other devices to check for its consistency and accuracy.

Keywords: nRF Transceiver, Weather Conditions, Weather Pico-satellite

1. INTRODUCTION

The weather satellite is a type of satellite that is primarily used to monitor the weather and climate of the Earth. Satellites can be polar orbiting, covering the entire Earth asynchronously, or geostationary, hovering over the same spot on the equator. [**1**]

Meteorological satellites see more than clouds and cloud systems: city lights, fires, effects of pollution, auroras, sand and dust storms, snow cover, ice mapping, boundaries of ocean currents, energy flows, etc. Other types of environmental information are collected using weather satellites. Other environmental satellites can detect changes in the Earth's vegetation, sea state, ocean color, and ice fields.

A CubeSat (U-class spacecraft) is a type of miniaturized satellite for space research that is made up of multiples of 10 cm × 10 cm × 11.35 cm cubic units. CubeSats have a mass of no more than 1.33 kilograms per unit [**2**], and often use commercial off-the-shelf (COTS) components for their electronics and structure. CubeSats are commonly put in orbit by deployers on the International Space Station, or launched as secondary payloads on a launch vehicle. Over 1000 CubeSats have been launched as of January 2019. Over 900 have been successfully deployed in orbit and over 80 have been destroyed in launch failures.

This project involves creation of a model of a Pico-Satellite which can be used to determine weather and pollution level of a small geographical area. The satellite will be a cube of 10 cubic centimeters dimension. It will contain three solar panels along with a Li-ion battery, chargers, voltage regulators as well as a boost converter for power supply, AVR as main controller, temperature, barometric, humidity, dust and lux intensity sensors, rain detector, along with nRF transceiver for transmission. The data will be displayed on a PC at the ground station through a GUI or a serial monitor.
For further details, section II explains the literature review, section III focuses on the methodology of the system while section IV illustrates the results and discussions. Section V includes the possible future enhancements and Section VI concludes the report.

2. LITERATURE REVIEW

NepaliSat-1, also known as Bird NPL, is a Nepalese low orbit research satellite and the first satellite of Nepal. [**5**] The nano satellite was developed by two Nepalese scientists Aabhas Maskey and Hariram Shrestha, both of whom are currently studying at Japanese Kyushu Institute of Technology. Aabhas Maskey, a PhD candidate in space engineering is the project manager of Bird-3 Project and he involves himself in this project. The satellite has a mass of 1.3 kg and funded by the Nepal Academy of Science and Technology while it was constructed under the BIRDS-3 project of the Japanese Kyushu Institute of Technology. The main mission of BIRDS Project Program was to support to that country who has never sent their satellite to space. The development of the satellite cost nearly twenty million Nepalese rupee. The satellite weights about 1.3 kilograms. The satellite contains Nepal's flag and Nepal Academy of Science and Technology (NAST) logo, alongside the developers name. The satellite was launched April 18 at 2:31 am (Nepal Standard Time) from Virginia. [**6**] The satellite will be orbiting at an altitude of about 400 kilometres. [**5**]
The Department of Hydrology and Meteorology in Nepal has installed weather radar and radiosonde balloons with the aim of making weather forecasting 100 percent accurate. Weather radar, also called weather surveillance radar is used to locate precipitation, calculate its motion, and estimate the type of rain, snow and hail. Weather radars are capable of detecting the motion of rain droplets in addition to the intensity of the precipitation. Radiosondes are carried aloft by balloons to measure and simultaneously transmit recorded data, which includes pressure, temperature and humidity. Winds are determined by using an instrument that tracks the radio signal transmitted from the radiosonde, or an inertial navigation system that transmits accelerations, or a GPS receiver that transmits the radiosonde’s locations. The radiosonde is attached to a hydrogen-filled balloon, generally called a weather balloon, and the balloon lifts the radiosonde to altitudes exceeding 115,000 feet. During the radiosonde’s ascent, it transmits data on temperature, pressure, and humidity to a sea, air, or land-based receiving station. [**7**]

3. METHODOLOGY

The architecture of the system as well as all the components used in the system is described in this section.

3.1 SYSTEM ARCHITECTURE

In the system, some physical quantities like internal and external temperature, pressure, height, humidity, light intensity, percentage of dust as well as occurrence of rainfall are measured or detected by their respective sensors and the data taken will be analyzed by the microcontroller for determining the values of those physical quantities which may not be directly provided by the sensor.

The data from the sensors will then be transmitted to the ground station using nRF transceivers. At the ground station, the data received by the microcontroller through the receiver will then be displayed on a serial monitor and saved in a text file for further use.

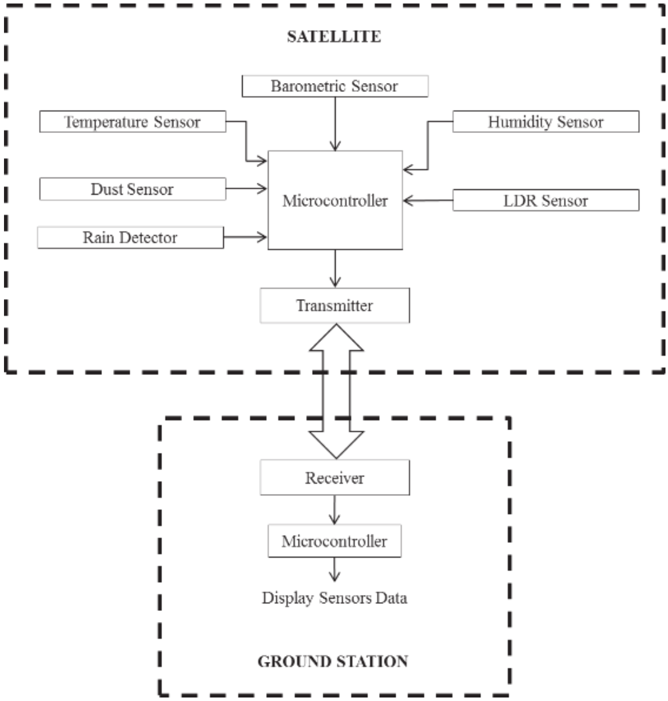

Figure 1: Block diagram of the system

3.2 INSTRUMENTATION

Various hardware components have been used in this system. They include the sensors, the controller, the transceiver and other components.

3.2.1. Frame:

The Satellite frame was made by 3-D printing required parts using Polylactic Acid (PLA) as feedstock material. The parts were then connected together after placing other hardware components in their respective position. After that the cube-sat has been covered with aluminum foil tape for insulation as well as to prevent combustion. The satellite has flaps that are initially closed but are programmed to open when required to expose the solar panel to light.

3.2.2. Power Supply:

A 3.7V Li-ion battery has been used as the main power supply. The DC voltage is converted to the 5V using a power bank module. The 3.7V and 5V voltage are used to supply power to the sensors as well as the controller as per required. The 5V is further converted to 12V using an adjustable boost converter for driving the heater as well as the fan. The 5V supply is also regulated to 3.3V using AMS1117 voltage regulator. Three Solar panels are used in order to charge the battery for the satellite to have independent power supply. The Solar panels provides 9V output at 500 mAh to the battery charging circuit.

3.2.3. Sensors:

Temperature Sensor (LM35): LM35 is used to measure precise centigrade temperature. The output of this sensor changes describes the linearity. It can detect temperature with range -55˚ to +150˚C. It was operated using 5V. LM35 is interfaced directly with the microcontroller and the analog data it gives in voltage was converted to Celsius temperature.

Barometric Sensor (BMP180): The BMP180 consists of a piezo-resistive sensor, an analog to digital converter and a control unit with E2PROM and a serial I2C interface. It provides the uncompensated value of pressure and temperature. The microcontroller sends a start sequence to start a pressure or temperature measurement. After converting time, the result value (pressure or temperature respectively) can be read through the I2C interface. It gives temperature in Celsius as well as absolute pressure in hPa that varies with altitude. By using a predetermined baseline pressure, relative pressure as well as altitude was calculated.

Humidity Sensor (DHT11): The humidity sensing component of the DHT11 is a moisture holding substrate with the electrodes applied to the surface. When water vapor is absorbed by the substrate, it releases the ions, which increases the conductivity between the electrodes. The change in resistance between the two electrodes is proportional to the relative humidity.

The resistance between the electrodes is inversely proportional to the relative humidity. DHT11 is interfaced directly with the microcontroller by decreasing input current using 1K resistor. It gives temperature as well as relative humidity.

Optical Dust Sensor (GP2Y1010AU0F): GP2Y1010AU0F contains an infrared emitting diode and a phototransistor which are diagonally arranged into this device, to allow it to detect the reflected light of dust in air. The output of the sensor is an analog voltage proportional to the measured dust density. GP2Y1010AU0F is interfaced with the microcontroller directly as per its datasheet using 150 ohm resistor as well as 220 microfarad capacitor for the pulse drive of the LED.

Light Dependent Resistor (LDR): This resistor works on the principle of photo conductivity. It is nothing but, when the light falls on its surface, then the material conductivity reduces and also the electrons in the valence band of the device are excited to the conduction band. These photons in the incident light must have energy greater than the band gap of the semiconductor material. This makes the electrons to jump from the valence band to conduction.

These devices depend on the light, when light falls on the LDR then the resistance decreases, and increases in the dark. When a LDR is kept in the dark place, its resistance is high and, when the LDR is kept in the light its resistance will decrease. If a constant V is applied to the LDR, increase in the intensity of the light increases the current. The figure below shows the curve between resistances vs. illumination curve for a particular light dependent resistor. The LDR is directly interfaced with the microcontroller using a voltage divider circuit with a 10K resistor.

Rain Detector: A rain detector contains an electronic circuit used as switch and a transistor, the output from the normally open circuit is fed to the base of an NPN transistor. The circuit has a 5V input and is designed to be closed when water falls on its surface. When the circuit closes, the current in the base of the transistor causes the current from collector to the emitter.

The voltage at the emitter side of the transistor in the Rain Detector is checked using the microcontroller. If the voltage is found to be high, it means there is rainfall.

3.2.4. Controller:

The microcontroller (Atmega328) is interfaced with all the other electronic components and takes data from the sensors as specified earlier and transmits them through the transmitter.

3.2.5. Transceiver

The nRF transceivers are interfaced with the microcontroller using SPI interface. They are operated at low power level because the power supply on the satellite is not enough for high power level. The data transfer speed is maintained at 250 kbps even though transmission rates are possible. This was done to increase the range as range is inversely proportional to data transfer rate.

3.2.6. Ground Station

In the Ground station, microcontroller, with an nRF receiver, is connected to a PC which also functions as the power supply. The data received is displayed in the serial monitor and saved as a text file.

3.2.7. Other Components:

A Heating Coil is used in order to maintain a suitable internal temperature for proper operation of internal components including the battery by increasing the temperature when required. A fan is also used for decreasing the internal temperature for the same purpose. The fan is also used to direct the dust particles to the dust sensor.

3.3 SOFTWARE USED

AutoCAD Fusion 360 was used to make the parts of the frame and Proteus Design Suite was used for circuit design. The microcontrollers were programmed in C language using Arduino IDE. In the program, a structure was created as follows containing variables to store all the data that can be measured using the sensors. Then subsequent values were measured using the sensors and stored. Then these data was then sent from the transmitter to the receiver. The process of determining the values through the sensors and transmitting was run on a loop for continuous inflow of real time data. At the receivers side similarly the data received from the receiver were stored in a similar structure, displayed in the serial monitor and saved in a text file.

4. RESULTS AND DISCUSSION

The main hardware body consisting of the skeleton and circuits with all devices has been properly constructed. The Cube-Sat frame was made by 3-D printing required parts and connecting them together after placing other hardware components in their respective position as shown in the figure.
The Cube-Sat was deployed by using a drone, to an altitude somewhat below the maximum altitude allowed for its flight, for observation of the result as well as its analysis. The drone in use was available to the team members prior to the beginning of this project and is not a part of it.

Figure 2: Top view and Side view of the Cube-Sat

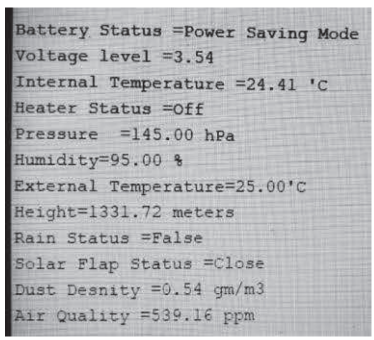

Figure 3: Screenshot of the data observed

The data obtained was analyzed to measure its consistency and accuracy. The results found after comparing the data obtained from various instances of time are discussed below.

All the data except air quality were found to have very low standard deviation. Even those low deviations were due to the higher sensitivity of the system such that slight movement (due to wind, etc.) would cause a change in its measurement. The air quality is prone to high change as the concentration of dust particles is not uniformly distributed. This is the reason for such high deviation.

Moreover, while the observed relative humidity was found to be much consistent, such is not the case all the time as was found out by observations different from the one shown above which, unfortunately, were not recorded. This is also for similar reasons as the one prior as the absolute density of water vapor can change depending on slight environmental changes.

The temperature observed using a room thermometer showed a temperature of 27 degree Celsius which is about the same as measured by our system. Also, the pressure observed by using the inbuilt sensor in a mobile phone showed 870 hPa pressure which is not much higher than the values we observed. The error is less than 1%.

From the analysis of the observed data, we concluded our system to be a feasible one.

5. FUTURE ENHANCEMENT

This project can be implemented for any remote sensing as meteorological purposes. Moreover, this project can be updated in near future as and when requirement for the same arises. The following are the future scope for the project.

Transmission of large data like image, voice, video, etc. is possible by splitting the data into smaller parts (the maximum size that can be transmitted at once) and transmitting them one by one. This may take time but optimization methods for increasing effective transfer rate can be done to minimize the time taken.

Use of other types of transceivers supporting higher transfer rate or higher range is also much viable. Our project uses nRF transceivers which have range about 1 km and maximum rate about 2 Mbps which is only possible on a much shorter range. So, other better devices for transmission may be implemented.

Use of high range antennas for properly capturing the entire transmitted signals with minimum loss and maximum range is also possible. This will decrease the hardware requirement on the module itself while maximizing its efficiency.

Our project measures and transfers weather related physical quantities. These data can be used in weather forecasting. With sufficient data, implementation of algorithms for weather prediction becomes possible even without the use of complex numerical models.

Sensing devices such as RADAR or LIDAR and so on can be integrated in the system. Since the system is a model for a Pico Satellite, implementation of such detection devices will have more relevance than otherwise.

6. CONCLUSION

This project demonstrates a model of a Cube Sat with all the required hardware parts. The system in this project also implements measuring of physical quantities for determining the weather conditions and pollution level at the location of the satellite, as well as long distance transmission of the data measured. In this regard, this system can be used to monitor the weather condition in real time.

The analysis of the data shows that the system provides consistent and relevant measurement of those physical quantities. The experiments conducted have affirmed the good performance of the system.

Hence, this system can be taken as a positive albeit small step taken towards the fields of satellite engineering and long distance data transmission.

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