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Nepal's Danfe Space Mission: Technology Demonstration Mission on a 3U CubeSat to Mitigate Glacial Lake Outburst Floods

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ABSTRACT

The United Nations Development Program ranks Nepal as the fourth-most country susceptible to climate change. The Global warming has caused more than 40 glacial lakes to potentially burst at any moment. A few Early Warning Systems are in place but are connected by ground cellular networks. A ground-to-space monitoring system instead, can help deter Glacial Lake Outburst Flood reliably. This paper outlines such a system through Nepal's Danfe Space Mission placed on a 3U CubeSat. Danfe demonstrates the first use case of ported PX4 drone Operating System alongside a LoRa integrated STM32 Satellite System-on-Chip. A Ground Sensor Terminal with ultrasonic sensor and LoRa beacons glacier water level data to space. If the demonstration is successful, future satellite constellations for monitoring glaciers can be produced in a significantly shorter period as both hardware and software are drastically simplified. Such constellations can provide near-real time water level data while inciting actions to prevent any impending flash floods.

Keywords: Glacial Lake, Nepal, Danfe Space Mission, PX4, LoRa, Satellite SoC

Acronyms

Commercially off-the-self (COTS)
Geographic Information System (GIS)
Glacial Lake Outburst Flooding (GLOF)
Inertial Measurement Unit (IMU)
International Centre for Integrated Mountain Development (ICIMOD)
Long Range (LoRa)
Low Power Wide Area Network (LPWAN)
Low-Dropout Regulator (LDO)
Multi-Payload CubeSat Platform (MPCP)
Operating System (OS)
Over Current Protection (OCP)
Satellite System on Chip (SSoC)
Satellite SoC Demonstration (SSD)
Universal Asynchronous Receiver Transmitter (UART)
Ultra-High Frequency (UHF)
Very-High Frequency (VHF)
Watch Dog Timer (WDT)

INTRODUCTION

In recent years, CubeSat are increasingly being used for earth observation and technology demonstration. The missions are for commercial and research purposes. CubeSats are small, agile, and have enough power to run a few missions in orbit.[1][2][3][4] CubeSats use COTS (Commercially off-the-shelf) components and the software is customized every time a CubeSat is designed. Flight data for electronics components and materials have been acquired after many successful CubeSat launches but the CubeSats still do not have a standard operating system.[2] On other hand, CubeSat has low power and small space which limits the capability.

2018 year is marked as first thousand nanosatellites were launched. The paper [2] presents the comprehensive survey of OS used as flight software on nanosatellites. The survey showed most of the satellite developer used open-source OS for reliability which benefited in limiting cost, not having to build OS from scratch and open-source community for technical support.[3]

The TRICOM project builds low-cost satellite communication system for development and educational purpose. The main mission was to provide data relay service for ground sensors using Long Range (LoRa) modulation and low power wide area network (LPWAN) which is limited to small data packets like temperature, humidity, etc. [1] BIRDS-2 initiated the Store and Forward (S&F) demonstration mission using Monopole antenna.[2] Later on, BIRDS-3 improved communication system in satellite by using dipole antenna and ground station by using circularly polarized antenna. The mission included Lora Demonstration Mission to verify LoRa RFM98 module can work in space.[4] BIRDS-4 S&F mission demonstrated data/message with Universal Amateur

Radio Text and Email messaging.[5] These papers verified the S&F technology using CubeSats.

In Nepal, there have been studies of glacial lakes with remote sensing and satellite imaging data. The dangerous lakes were identified from satellite images and the use of Geographic Information System (GIS) mapping tools but were recommended to monitor in the field.[6][7] The glacial lakes are mapped and labeled as potentially dangerous are well-defined criteria but they are not properly monitored. Early warning systems ground-based on cellular networks are used in some places of Koshi basins. The system consists of remote sensing stations with data loggers and transmits data on short-burst VHF radio signals. The ultrasonic sensors and float water level switch sensors are used to measure water level. When water level increases, the warning sirens are alarmed.[8] Such systems fail to work in long run and activates just before the disaster are going to occur. To predict the Glacial Lake Outburst Flooding (GLOF) and monitor glacial Lake over a long-distance, satellites are needed.

This paper presents a solution for the manufacture of GLOF monitoring CubeSat running ported open-source drone operating system, a merged onboard computer and communication single system and a Ground Sensor Terminal (GST) to mitigate GLOF in Nepal.

Problem Statement

The United Nations Development Program ranked Nepal as the fourth-most country susceptible to climate change. Glaciers are a sensitive indicator of global warming. Glaciers melting in the Himalayas have resulted in the formation of new glacial lakes and the enlargement of existing ones. Glacial lakes are unstable and can burst at any moment which causes a catastrophic source of disaster to people and their property down the valley.[6][7][8] Remote sensing and satellite imaging have shown hundreds of glacial lakes have formed in recent years. 47 glacial lakes in Nepal have been marked as potentially dangerous by ICIMOD. Since 1997, 26 GLOF events have been recorded in Nepal and 11 of these have had transboundary impacts [7]. Developing GLOF monitoring satellite is very costly and mission success rate is also very low. To develop low-cost satellite in short period it requires open-source flight software and low power miniaturized high performance electronics components.

Mission Objective

In 2018 Nepal launched NepaliSat-1 which is built under the BIRDS project. The NepaliSat-1 had imaging and LoRa demonstration for S&F missions. To keep the consistency of Nepal's space mission in orbit, the demonstration mission is designed for a Multi Payload CubeSat Platform (MPCP), a 3U CubeSat. The two-demonstration mission is to verify the system in space of future CubeSat System. The main objectives are:

A. Demonstration of CubeSat operating system using PX4 Autopilot operating system

B. Demonstration of Satellite System-on-Chip as Onboard computer and Communication system using single STM32WL55JC

C. Store and forward using Ground Sensor Terminal for glacial lake water level monitoring in the Himalayan region of Nepal

MISSION OVERVIEW

Payload

The payload is interfaced with the BUS system in PC/104 standard. The payload uses STM32F103C8T6 as the Main microcontroller for collecting housekeeping

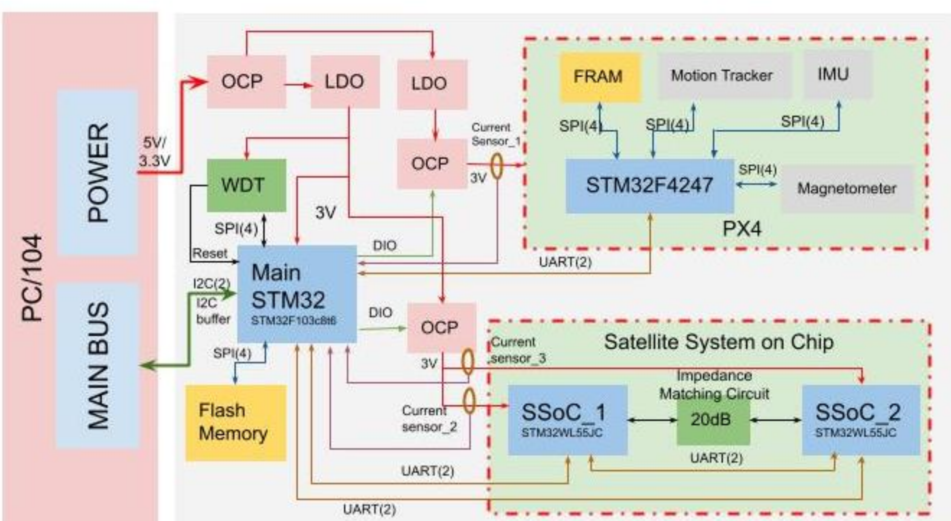

FIGURE 1: Working Block Diagram of Danfe Space Mission

data, data handling, and mission execution. The Main STM32 uses the I2C protocol to interface with the MPCP OBC as shown in FIGURE 1. The payload includes a watchdog timer for Main STM32 which can self-reset the payload in case of Single Event Effects (SEEs). A temperature sensor is included to monitor the temperature. Over-Current Protection (OCP) is used to control and protect the payload against current surges and turn on/off missions. The payload is equipped with 1Gb flash memory to store housekeeping and mission data. Main STM32 is in control of the flash memory and OCPs. Both the PX4 MSN and SSD MSN exchange data and commands with Main STM32 using the UART protocol.

MISSIONS DESCRIPTION

The Danfe Space Mission has two missions on board. They are the PX4 Autopilot Demonstration Mission (PX4 MSN) and Satellite System on Chip Demonstration Mission (SSD MSN).

PX4 Autopilot

The objective of the PX4 MSN is to use drone COTS components and a PX4 Autopilot, based operating system in CubeSat as a CubeSat operating system. The PX4 Autopilot is open-source software for drones developed by The Dronecode Foundation based on Linux. PX4 provides a flexible set of tools for drone developers allowing the use of plug-and-play systems.[9] The major problem with CubeSat development is that it repeats the development process for each individual mission of CubeSat. This results in each mission being costly both in finance and time. Each CubeSat mission also requires unique code as there is no standard OS available. This development of software generally requires more time than hardware, which also results in the extension of development time. The main goal of the PX4 MSN is to make a general operating software supporting modular plug-n-play CubeSat hardware to accelerate the development time.

Drones Vs CubeSats:

A. Drones have a massive community and mature open-source operating system, supporting plug-n-play systems contrary to CubeSats with a tightknit community and its unique set of hardware-software configurations.

B. Drones have modular systems and software where payload can be added/removed without changing design whereas CubeSats have to design from scratch in case of any changes

C. Drones have a simulation environment but CubeSats require space simulation which is expensive.

But there is still a lot of common between them which are:

D. Drones and CubeSats use COTS components so software and hardware design are similar

E. Both have payloads, transmit telemetry data and receive commands from the ground station

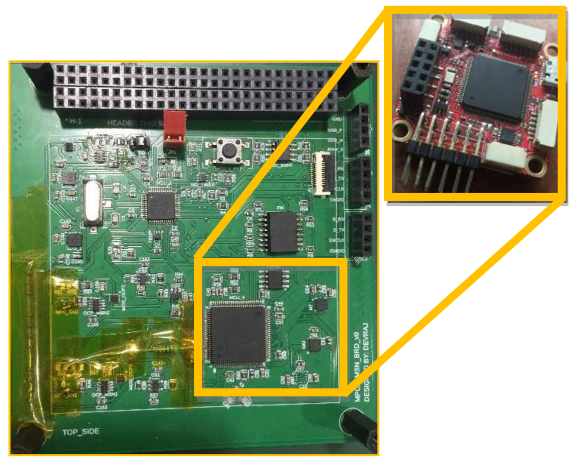

FIGURE 2: EM board Top side PX4 Mission

Inspired by PixRacer v1.0, the PX4 mission hardware is designed using PX4-compatible hardware. The PX4 uses an STM32F4247 microcontroller to operate the Motion Tracker, Inertial Measurement Unit (IMU), and Magnetometer. A FRAM is also included to store boot parameters and it is connected with SPI protocol. PX4 communicates with the main STM32 using MAVLINK over UART. The PX4 Autopilot collects housekeeping and sensor data. The MAVELINK protocol streams mission data to the main STM32, which then stores it in Flash memory. The purpose of the PX4 Autopilot mission is to demonstrate functional testing of PX4 compatible hardware and PX4 Autopilot operating system in a space environment.

Satellite System-on-Chip (SSoC)

The objective of the Satellite SoC Demonstration Mission is to verify performance of the single Novel STM32Wl55JC working as the Onboard Computer and Communication System of CubeSat. The hardware used in Satellite System on Chip is STM32WL55 (released on 2020 Nov) dual core processor with M0+ and M4 ARM Cortex which has built-in radio. The built-in radio supports GMSK, BPSK, GFSK, and LoRa Modulations with high receiver sensitivity. The SSoC demonstration mission consists of two STM32WL55JC. The main STM32 controls the mission operation. Both SSoC are connected with the main STM32 with UART protocol. Two SSoC named as SSoC_1 and SSoC_2 is connected with UART protocol and Radio lines of 50 Ohm impedance matching circuit on PCB with 20db attenuator between them. There is no LoRa modulated RF signal transmitted outside the payload.

SSoC Mission Operation

When the SSoC mission is operated, the SSoC_1 is initialized as a LoRa transmitter and SSoC_2 as a LoRa Receiver. The SSoC_2 has a 12-bit resolution ADC that calibrates and measures its internal temperature. It creates 42-byte long data packets, including packet header and repeating data header, and temperature data. The data packet is then transmitted via LoRa modulation to SSoC_2. The LoRa is transmitted in low power mode and a 20dB attenuator is put in the coplanar RF line. The SSoC_2 LoRa receiver receives 42 bytes of data and then forwards the data packets via UART protocol to SSoC_1.

The SSoC_1 will compare the transmitted data and received data from SSoC_2. SSoC_1 checks each byte

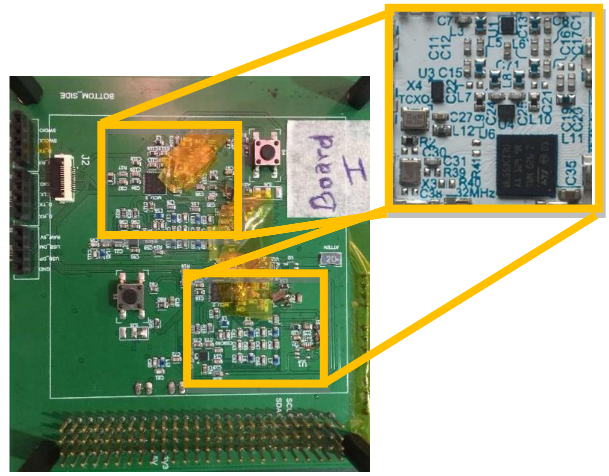

FIGURE 3: EM board Bottom side SSoC Mission

in data packet loss and efrrors and sends mission data to the main STM32 via UART. The main STM32 writes mission data in flash memory. If an error in the data packets is found, the data header is changed and marked with an error rate. Similarly, after completing one round of missions, the SSoC_1 is changed to LoRa receiver and SSoC_2 to LoRa transmitter. Then the mission continues to make 4Kb data and store mission data in Flash memory.

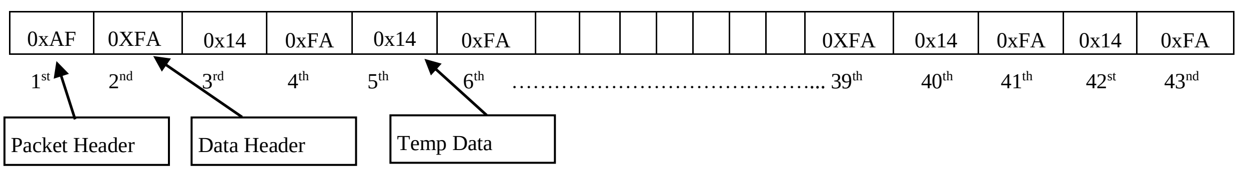

FIGURE 4: SSoC LoRa transmit 43 bytes data packet

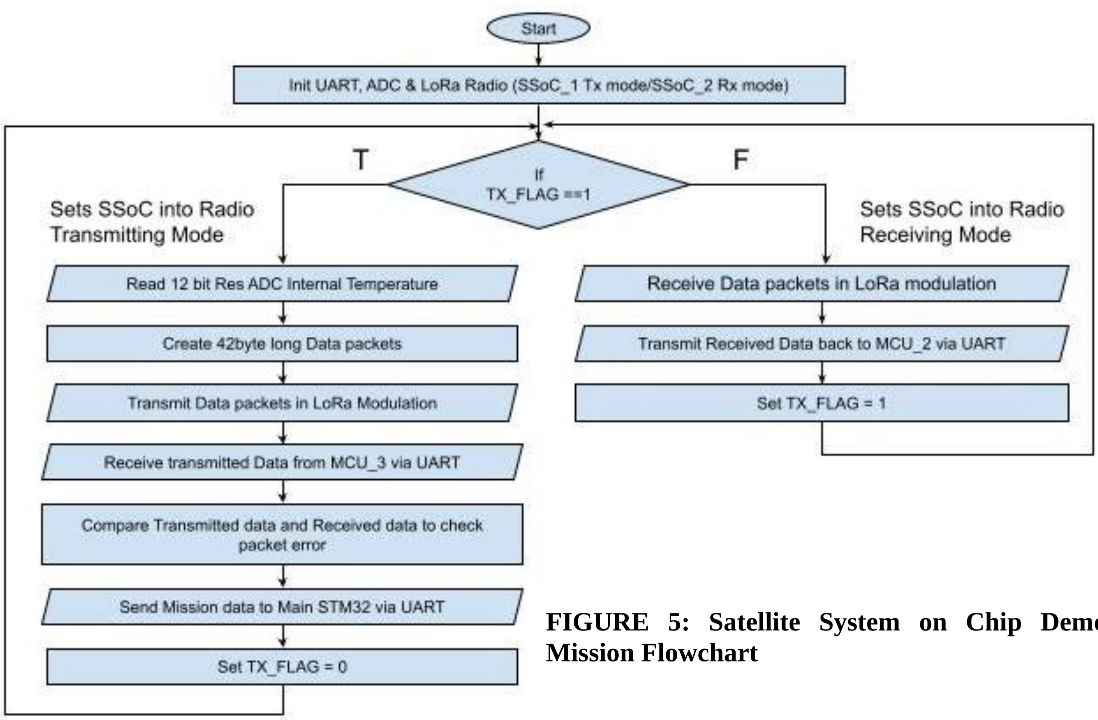

FIGURE 5: Satellite System on Chip Demonstration Mission Flowchart

Glacial Lake Outburst Flooding Mission

The main objective of the GLOF monitoring mission is to collect the data on the remote Glacial lakes with no other means of communication. GST deployed in such glacial lakes, collect the environmental parameters and uplink them using LoRa modulation in the UHF frequency band. This data can be useful to study the changes in the lakes happening over time and predict GLOF. The system is to be tested using the KITSUNE satellite (6U CubeSat developed by KYUTECH and launched in Feb 2022). The uplinked data is then received by satellite, stored, and forwarded to the Ground Station from where it can be distributed to the concerned parties.

GST consists of an Ultrasonic sensor to measure the lake's water level. Additional sensors for temperature, humidity, and soil moisture data collection are also used. A Real-Time Clock is used to keep track of the time in GST. All data are collected and logged in an SD card, including timestamps, simultaneously transmitted using LoRa modulation. The system is powered using the onboard power system consisting of a 20W solar panel and 12V li-ion battery pack, which can store the energy enough to power up the system for four days without charging.

Parameters	**Specification**
Microcontroller	ATMEGA328p
Sensors	Ultrasonic sensor, Temperature, humidity, Real time Clock
Storage	8GB microSD card
Modulation	LoRa
Operating Frequency	433MHz
Data Rate	300kbps
Power	12V, 500mA battery / 20W solar panel
Interface	SPI, ADC, UART

TABLE 1: GST Specification

CONCLUSION

Danfe Space MSN incorporates two technology demonstration mission: PX4 Autopilot mission and SSoC Demonstration Mission. Along with the usage of GST for glacial lake monitoring and GLOF prediction. These missions will produce essential data which will allow for the speeding up CubeSat design and also provide higher mission capacity resulting from reduced Bus Design. Prediction of GLOF allows for implementation of disaster mitigation measures which directly results in significant reduction in loss of life and property.

At the time of writing, Danfe Space MSN is ready for flight model development and deployment. The expected mission duration of Danfe Space Mission is 2 years in Low Earth Orbit where it will collect operation data of PX4 Autopilot and data error rate measure of SSD Mission. Danfe Space Mission is expected to be launched by December 2022.

Acknowledgments

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References

1. Quentin VERSPIEREN, Takeshi MATSUMOTO, Yoshihide AOYANAGI, Takayoshi FUKUYO, Toshihiro OBATA, Shinichi NAKASUKA, Georges KWIZERA, and Joseph ABAKUNDA, "Store-and-Forward 3U CubeSat Project TRICOM and Its Utilization for Development and Education: the Cases of TRICOM-1R and JPRWASAT*," Trans. Japan Soc. Aero. Space Sci. Vol. 63, No. 5, pp. 206–211, 2020
2. Kiran Kumar Pradhan, BIRDS-2 members, BIRDS Partners, Faure Pauline, George Maeda, Sangkyun Kim, Hirokazu Masui, Mengu Cho "BIRDS-2: Multi-Nation CubeSat Constellation Project for Learning and Capacity Building," 32nd Annual AIAA/USU Conference on Small Satellites, 2018.
3. Abhas Maskey, Maisum Ibn Monowar, Mengu Cho, "The First Thousand Nanosatellites: A Study of Operating System Used," Department of Applied Science for Integrated Systems Engineering, Kyushu Institute of Technolgy, Japan, 21st June 2019
4. Makiko Kishimoto, Tharindu Lakmal Dayarathna Malmadayalage, Abhas Maskey, Pooja Lepcha, Dulani Chamika Withanage, Yuta Kakimoto, Yuji Sasaki, Hari Ram Shrestha, BIRDS Partners, George Maeda, Takashi Yamauchi, Sangkyun Kim, Hirokazu Masui, Mengu Cho, "Improvement of Communication System for 1U CubeSat," 34th Annual Small Satellite Conference, 2020
5. Adolfo Javier Jara Cespedes, Izrael Zenar Casople Bautista, BIRDS-4 Project Members, George Maeda, Sankyun Kim, Hirokazu Masui, Takashi Yamauchi, Mengu Cho, "An Overview of the BIRDS-4 Satellite Project and the First

Satellite of Paraguay," 35th Annual Small Satellite Conference, 2021

6. Sudan Bikash Maharjan, Pradeep Kumar Mool, Wu Lizong, Gao Xiao, Finu Shrestha, Rajendra Bahadur Shrestha, Narendra Raj Khanal, Samjwal Ratna Bajracharya, Sharad Joshi, Sonika Shahi, Prasant Baral, "The Status of Glacial Lakes in the Hindu Kush Himalaya," ICIMOD Research Report 2018/1

7. Bajracharya, S.R., Maharjan, S.B., Shrestha, F.,Sherpa, T.C., Wagle, N., Shrestha, A.B., "Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali River Basins of Nepal, the Tibet Autonomous Region of China, and India," Research Report. ICIMOD and UNDP 2020.

8. Jack D. Ives, Rajendra B. Shrestha, Pradeep K. Mool, "Formation of Glacial Lakes in the Hindu Kush-Himalayas and GLOF Risk Assessment," International Centre for Integrated Mountain Development, Kathmandu, May 2010

9. Gijs van Esch, Dirk van den Heuvel,"PX4 AUTOPILOT ON A UAV CONTROLLER Flying a Xilinx ZU7EV based processing board," 2021 WHITE PAPER

10. https://Px4.io, "Open-Source Autopilot for Drone Developers," https://github.com/PX4/PX4-Autopilot