Title: CUBESAI: CubeSat-based Sensing and AI for Disease Prediction

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Need

Vector-borne diseases are human illnesses caused by parasites, viruses, and bacteria that are transmitted by vectors. There are more than 700,000 deaths from diseases such as malaria, dengue, chikungunya, yellow fever, and Zika every year [1]. Lack of resources prevents effective control of these diseases, and they not only put human health at risk but also greatly affect other areas of the world like the economy [2]. Scientists can determine where disease-favoring conditions in the environment exist, and that can only be done by a global surveillance system that satellites provide [3].CubeSats are convenient and highly capable of making such measurements (such as temperature, humidity, etc.) for Low Earth Orbit weather observations. A constellation of satellites enables us to cover all high-risk areas where diseases emerge quickly and simultaneously. Also, CubeSats are preferred for this mission due to their updateability, lower cost, and easier production than larger space systems. Moreover, current large space systems do not fully address the requirements that are mentioned.

Mission Objectives

Primary Objective

The main purpose of CUBESAI is to provide wide coverage of high-risk areas and rapid data compilation with a constellation of satellites since vector-borne diseases change and adapt quickly to new conditions. Multiple CubeSats in three different orbits are essential to rapidly acquiring data when covering all the high-risk areas.

A similar project that studies vector-borne diseases using a Cubesat is CHIKRisk, which provides monthly outlooks on where chikungunya risk is highest around the world. It successfully assessed the risk for chikungunya in several countries around the world [3].

Similar to CHIKRisk, CUBESAI will measure geo-environmental conditions (such as temperature, humidity, precipitation, etc.) associated with brutal diseases with multiple CubeSats in a large region of high-risk areas at the same time. CUBESAI will be able to predict all vector-borne diseases where CHIKRisk only assessed chikungunya disease. Therefore, CUBESAI will not only predict present diseases with its advanced technological contents but also prevent vector-borne diseases before they become epidemics.

Secondary Objective

The distribution of vector-borne diseases in the world consists of variable climate types. For instance, Africa and South America are both high-risk areas; however, the weather in those countries is usually different from each other. Collecting data uninterruptedly for this mission is needed; however, not every sensor operates efficiently in every condition. Thus, when using traditional instruments, different methods should be used to prevent such a risk. Remote sensing instruments provide more comprehensive and uninterrupted data than traditional CubeSat instruments in a quicker way. Remote sensing instruments can collect data as a set; however, not all of them can operate efficiently in every condition. For example, while active remote sensing equipments are able to collect data in rainy weather, passive remote sensing instruments are not. Hence, in order to maximize the efficiency of the collected data simultaneously, the instruments are split into two different types of satellites (3 CubeSats for each).

CUBESAI-P is equipped with passive remote sensing sensors and will be able to measure:

- Temperature, humidity, and precipitation by microwave radiometer; wet zones; sky clearness (cloud properties), increased temporal resolution images by hyperspectral imager; and latitude by GNSS.

CUBESAI-A is equipped with active remote sensing sensors and will be able to measure:

- Temperature, humidity, topography, soil moisture, vegetation by SAR, H2O vapor, and wind by scatterometer.

Organizing them in this way will have three benefits.

1. Collecting data at every point on our route, regardless of any condition on Earth, without interruption.
2. Since some of our active and passive remote sensing instruments are capable of doing the same measurement under different weather conditions, we will have proven data. Moreover, if CUBESAI-P fails, CUBEASI-A can fill its void. The same is valid for reverse.
3. At the end of the mission, we will have a chance to compare active and passive remote sensing sensors efficiency using utility data given to us during our mission.

Third Objective

As an active remote sensing sensor, using synthetic aperture radar (SAR) has the advantages of getting images that are independent of sunlight and can see through (penetrate) clouds, which makes it a reliable sensor that provides a measurement every time [4].

Concept of Operations

Launch and the Beginning of CUBESAI

Since CUBESAI will operate in Earth orbit, CubeSats can be launched without any restriction as long as they are placed in their orbits in pairs. The deployer will leave our satellites in the mission orbits in groups of two. Therefore, there is no need to allocate a budget for Delta-V and fuel. A short time after the deployment of our first group of CubeSats, every element of them and their communication with the ground system will be checked. After this procedure is done,

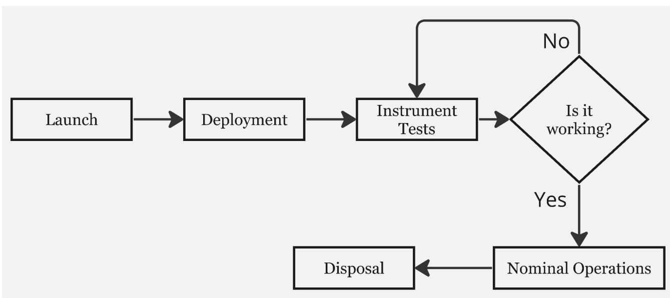

Figure 1: CONOPS Diagram

our satellites will be commissioned, and data transfer will start. The same plan will be applied to both pairs.

Ground Segment

SpaceWire was selected as the communication protocol for our CubeSat project based on its proven reliability, efficiency, and suitability for space applications. Its high-speed transmission capabilities and low-power requirements optimize data transfer while conserving valuable onboard resources. Moreover, the chosen S-Band is a frequency range commonly used for satellite communication, providing a balance between signal strength, bandwidth, and power requirements. It ensures reliable and stable links between CubeSats and ground stations, facilitating efficient data transmission. On the ground, the system is divided into two main components: the AI ground system (AIGS) and the Flight Operations ground system (FOGS). The AIGS consists of three elements: data processing, backup, and the Disease Prediction Unit (DPU). Data processing handles the raw data from the CubeSats, performing tasks like cleaning, normalization, and transformation. The backup system ensures secure storage and replication of data.

The DPU utilizes AI algorithms and machine learning to analyze the processed data, generating accurate disease predictions based on health data and weather patterns. The FOGS focuses on controlling and managing the CubeSats. It receives data on position and health status, enabling orbital monitoring and control.

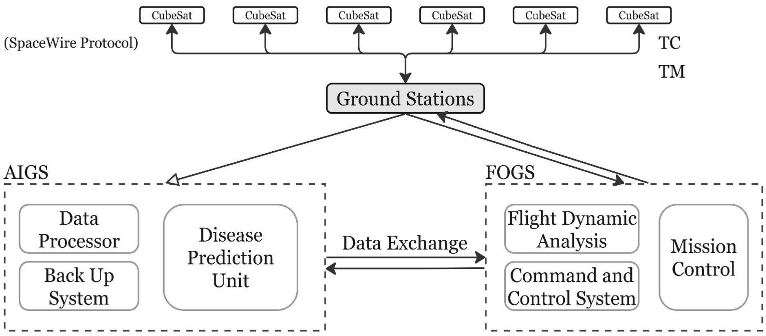

Figure 2: Collaboration of AIGS, FOGS, and CUBESAI

Space Segment

Our operation consists of two types of 3U CubeSats, namely CUBESAI-P and CUBESAI-A, three of each, operating around 600 km altitude as a constellation. Our constellation measures wanted specific parameters that are related to disease formation in detail and high-resolution.

Key Performance Parameters

1. CUBESAI will cover three different orbits in order to collect data from all high-risk areas.
2. CUBESAI's remote sensing sensors should be able to deliver data successfully.

Space Segment Description

Structural Elements and communication system information:

	Mass (kg)	Power Consumption (W)
Structural Elements		
Commercial Modular Frame	0.29	
ADCS System		
Star Tracker	0.04	0.6
Magnetometer	0.012	0.5
Sun sensor*6	0.03	<0.2
Gyroscope	0.9	5
Reaction Wheels*3	0.18	1.95
Magnetorquer*3	0.3	0.3
Communication System		
Transmitter	0.07	1 - 2.5

Table 1: Structural Elements

CUBESAI-P

CUBESAI-P carries a payload of passive remote sensing sensors that weigh 2.01 kg and have a maximum 2.825-7.125 W power consumption. Adding structural elements, the total weight and total power consumption of CUBESAI-S are 3.832 kg and 10.275-16.275 W, respectively. CUBESAI-P includes the TROPICS mission’s microwave radiometer, which can serve our purpose very well [5].

	Description	Mass (kg)	Size (m*m*m)	Power Consumption (W)
Passive Remote Sensing Sensors				
Microwave radiometer	TROPICS's microwave radiometer	1.33	0.1*0.1*0.1	
Hyperspectral imager	HyperScape50	0.44	0.0959*0.0902*0.1175	2.7 when idle, 7 when imaging
GPS	GNSS Receiver	24	0.04573*0.072*0.02	0.125 average

Table 2: Passive Remote Sensing Instruments

CUBESAI-A

CUBESAI-A carries a payload of active remote sensing sensors that weigh <2 kg and have a maximum power consumption of 9 W without structural elements. Adding structural elements, the total weight and total power consumption of CUBESAI-A are 3.622 kg and 18.5-20.05 W, respectively.

Active Remote Sensing Sensors	Description	Mass (kg)	Size (m*m*m)	Power Consumption (W)
SAR	custom	1.2**	0.1*0.1*0.2	4**
Scatterometer	custom			5**

**estimated

Table 3: Active Remote Sensing Instruments

Orbit/Constellation/Description

The focus of research is mainly on the Equatorial Region since the data indicates that the majority of diseases appear here (Figure 4). Since the weather data is a dynamic variable, constant data on particular areas where the diseases have most emerged is needed to determine conditions that are susceptible to illness. Thus, three elliptical orbits, around 600 km and 25° inclination are determined for three couples of CubeSats. Elliptical orbits were adjusted to decrease interference and increase CUBESAI's coverage and data resolution in potentially risky areas. The Orbital Elements and a picture of orbits are given (Figure 3).

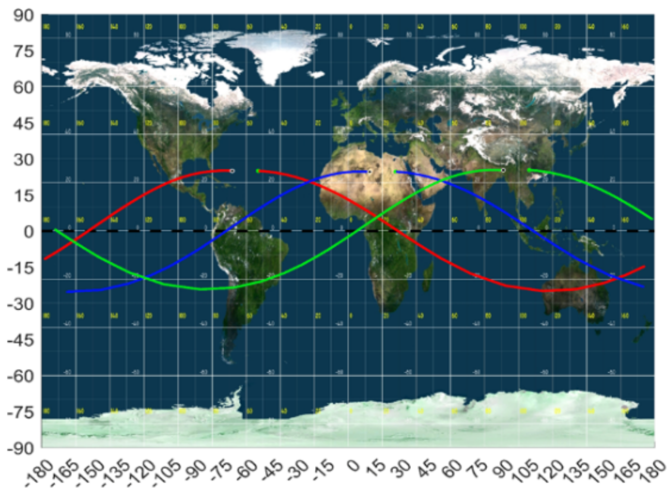

Figure 3: Orbitals of CUBESAI

Orbital Elements	Blue	Green	Red
Eccentricity	0.676	0.676	0.676
True Anomaly Initial (deg)	208.5	208.5	208.5
Period (s)	3742.1	3742.1	3742.1
Semimajor axis (km)	5209.6	5209.6	5209.6
Inclination (deg)	25.048	24.875	25.053

Table 4: Orbital Elements of Orbits

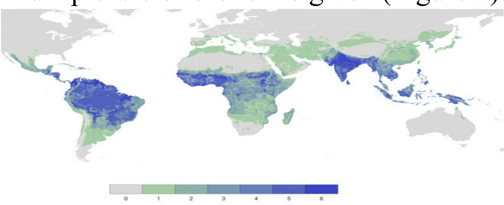

Figure 4: Distribution of Vector-Borne Diseases in the World[2]

Implementation Plan

During our flight, three types of data will be used and interpreted by AI: known data (major habitat type), data taken from ground sources (air pressure, deforestation, migration, artificial water, uncontrolled agriculture fields), and collected data using CUBESAI (temperature, precipitation, humidity, wet zone, cloud information, latitude). Since CubeSats are short-termed satellites and our flight duration would be lower than determining clues of various diseases, AI would be equipped with past years data to detect anomalies. A collaboration with the World Meteorological Organization (WMO) or national weather services will contribute to the mission and speed up the process. The estimated total life cycle cost that includes design, development, assembly, integration, testing, launch, operations, and disposal of each CUBESAI is roughly 0.85 million dollars. When the project is applicable, it can help other constellation missions cover a wide range of areas rapidly and share the advantages and disadvantages of passive and active systems. This is useful for other observation missions in a wide range of meteorological conditions.

Top 5 major risks in increasing order:

1. Power system and attitude control failure
2. Communication system failure
3. Sensor failure
4. Data handling failure
5. Mechanical failure

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