CubeSat Network for Real-time Ionosphere Monitoring and Prediction of Earthquakes

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Outline

This nano-satellite mission is to design LEO satellite network consisting of 120 of 2-unit cube satellites that can obtain global ionospheric plasma map simultaneously with geographic map. Satellites will measure electron density and temperature using TeNeP – the new equipment free from error due to contamination. The inter-satellite region will be also monitored by total number of electrons integrated between points using phase delays of radio wave through a medium. Additionally, we will use camera of field of view 115 degrees with resolution of 3.5 degrees to make geographical map of the Earth. Moreover, based on the study that the ionospheric anomalies can be interpreted as earthquake precursor, it might be used to establish the pre-alarm system for earthquakes

1. Aims and significance

ⅰ. Aims

South Korea has been originally considered as an earthquake-free country compared to its neighbor Japan. However, since the recent earthquakes which are with Richiter magnitude over 5, the interest in earthquakes are higher than ever. The best would be preventing it, which is impossible, but predicting it might be possible. Suaradi et al. (2018) showed the relationship of between ionospheric Total Electron Content (TEC) variations and earthquake events. According to the study, TEC anomaly was observed before the earthquake event within the range of 1 day~2 weeks which could be noticed by rapid rise or fall of TEC values. It was also seemed to occur only during the earthquake of Richiter magnitude over 4.0. However, it is difficult to understand well the ionospheric variations, and the coupling processes between the ground motion and ionospheric dynamics comprehensively. So we have thought it would be useful to establish an ionosphere network system using CubeSats that can observe over all ionosphere in real-time – along with cameras that can provide the earth's geographical map.

ⅱ. Importance, technical significance

CubeSat is a type of nano satellites developed for educational purposes at first, but now is trending around the space industries including NASA and SpaceX, being considered as a new field of space exploration due to its strength despite its size. We also plan to use CubeSats, as they are appropriate for constructing the ionosphere network system. As they are small – 10cm x 10cm x 10cm in volume and 1.33kg per unit – it costs only 26,000 USD for each launch. This is big advantage when it comes to developing network system as it requires multiple satellites. The number of CubeSats will cooperate with each other, communicating instantly, to carry out its mission. We have planned to use a TeNeP module to measure ionospheric electron density and temperature, and a RF module (radio frequency module) for inter-satellite TEC. They will be loaded to every CubeSat, forming a single large network system that could observe the ionospheric activities.

2. Outline of idea

ⅰ. Satellite design

CubeSat used in our mission is 2 unit satellites, with mass approximately 2kg. The Attitude Control System (ACS) is what also matters as proper orientation is required for each CubeSat to function properly and maximize its energy efficiency. Recently satellite's attitude control is done using reaction wheel or thrusters, which are kinds of active control. In addition, it is planned to use the omnidirectional antenna for satellite-to-satellite radio communication to enable inter-satellite communication.

To show feasibility of this model, we have designed a CubeSat model with the electron temperature and density probe (TeNeP), RF module, and optical camera to acquire earth images, as payloads. The satellite bus consists of Arduino, Bluetooth module (HC-06), reaction wheel with DC motor, and aluminum frame. Each part corresponds to elements of the CubeSat; Arduino is an on-board computer of satellite, Bluetooth module is for communication system, and reaction wheel is used to control the attitude of satellite. We could verify the practicality of CubeSat network from this model.

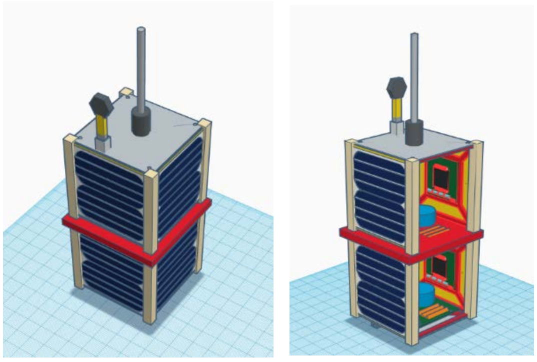

Fig 1. 2U CubeSat

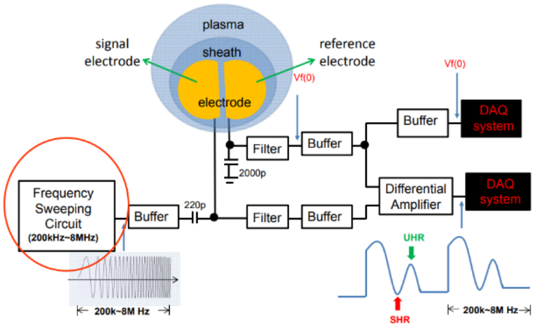

Fig 2. System configuration of TeNeP (Jiang et al., 2014)

ⅱ. Satellite network system

Fig 3. Satellite network in LEO

Our satellite network in LEO is carefully designed with mathematical calculations. First, local plasma measurements are done using the TeNeP, and the total number of electrons between satellites, defined as the inter-satellite TEC, are obtained by observing the phase delays of radio wave (RF module). From extending these method, we can derive the global map of ionosphere plasma, which can be used to investigate ionospheric variations.

Satellite constellation consists of 12 polar circular orbits with 5 pairs of CubeSats placed at constant intervals with 0.277° difference between the orbits to prevent their collisions. We have paired up the satellites for efficiency as Earth's rotation let it cover large area. Let parallelogram of side 3.6° and 5° be 1 cell comprising of 2 pairs of two satellites on adjacent orbits. This assures spatial resolution of 3.6° × 5° in latitude and longitude. Every CubeSats move 30° along the latitude every 2 hours and 72° along the longitude every 20 minutes. Which let the map of the whole ionosphere is refreshed every 2 hours.

ⅲ. The Electron Temperature and Density Probe (TeNeP)

The TeNeP, distinct from the Langmuir Probe (LP), uses plasma resonance for measurement of plasma characteristics. TeNeP obtains the electron temperature (T_e) by floating potential shift, and density (N_e) by upper hybrid resonance. The method called ‘frequency sweep’ from 200kHz to 8~10MHz is used in this process (Oyama et al., 2015; Jiang et al, 2014). The TeNeP will be mounted on each CubeSat for measuring the values of electron density and temperature.

The reason for using the TeNeP is due to technological limit of the LP. It is difficult to obtain accurate electron density and temperature using the LP for two major reasons: the contamination on the surfaces of the probe and satellite, and a lack of conductive surface area of the tiny satellite.

The probe is contaminated mainly with water molecules, layering on the surface with thickness about 20~80nm. However, when the layer thickness is 20nm on 25 cm^2 metal electrode surface, the effect of this contamination on capacitance is about 87μF – equivalent to 100~500$k\Omega$ resistance (Oyama et al, 2015). This leads to elevated T_e and suppressed N_e. Contamination can only be removed by plasma bombardment or baking in high vacuum, which is not possible on space.

Having not enough conducting area is also a significant problem of DC LP. The satellite will act as counter electrode, requiring ~100 times larger surface area compared to electrode for correct T_e measurement, and ~1000 times for correct N_e. This is because potential of electrode will decrease – collecting more ions from plasma.

That’s why we also need TeNeP, a contaminant-free instrument operated at 0.2~10 MHz probe sweeping frequency and sweeping potentials below 500 mV, which will help CubeSats with a surface ratio below 100 to function properly.

3. Anticipated results

The real-time CubeSat network will be constructed. As mentioned above, the large satellites are not suited for ionosphere observation network due to development and launch costs, and development period. Our project will allow observations of ionospheric activities. Moreover, the ionosphere plasma map will be obtained.

From various researches about ionosphere anomaly as the earthquake precursor, it has been suggested that ionospheric anomalies occur not only before earthquakes but also other supernatural disasters like Typhoon. So with the ionosphere map constructed, massive amounts of data can be collected leading to development of disaster predicting system.

4. Originality and Social effects

If the earthquakes can be predicted through our ionosphere network system, the damage would significantly decrease as we can prepare for it. For example, locals in the area could evacuate from earthquakes and Tsunamis, minimizing casualties. Also most ionospheric activities will be monitored, which leaves us with infinite possibilities.

5. References

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