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The autonomous system architecture of the small SAR satellite operation system and on-orbit autonomous operation experiences

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ABSTRACT

We are developing a small SAR (Synthetic Aperture Radar) satellite for our commercial solution business. Our goal is to deploy at least 30 small SAR satellites in orbit and enable frequent and regular observations by the Mid 2020s. We launched the first satellite on 15th December 2020 with Rocket Lab's Electron. After a wait of as security time to ensure a complete evacuation of the residual air and contaminations to prevent any hazardous electrical discharge, the first image was taken, on 8th February. The satellite is currently stably operating and acquiring images requested by our customers. A six-satellite constellation is planned to be deployed by 2023. We also describe our system architecture including our solution business and the satellite development. To thrive in a project of this nature, solid communication among the various stakeholders is instrumental to achieve an agile reflection of the user's needs on the satellite development. For instance, our business development team, which acquires novel needs from our customers, and the satellite development team are tightly connected to help the adequate system architecture and agile satellite development. We are now operating internally to establishing a process to extract those business needs, analyze them and identify the key requirements for the satellite performances and functions. We believe that one important challenge is to achieve application layer integration from a customer business system to a satellite on-board software within a technology environment grounded on a solution platform, a data platform, the satellite control ground system, and the satellite itself. Harmonizing the software and information processes of the application layer entails challenges as the platform where the application is located, the organization where the staffs belong, and their culture are all different. We wish our activities make a contribution to our small satellite community and advance our system architecture joining the efforts of our ecosystem including component suppliers, communication service providers, and data processing service providers.

INTRODUCTION

Synspective launched its first demonstration satellite, StriX-α, with Rocket Lab’s Electron from Mahia, New Zealand, on December 15, 2020. Photographs of StriX-α are shown in Figure 1. Right after the separation from the launching vehicle, the satellite’s SAR antenna (which undersides support the solar panels) deployment and sun pointing was automatically performed to ensure the safety of the satellite. After that, the satellite functions were checked out. After a wait of as security time to ensure a complete evacuation of the residual air and contaminations to prevent any hazardous electrical discharge, the first image was taken, on 8th February. That image shows the vicinity of the airport of Miami, Florida, shown in Figure 2. which also shows a Suez Channel picture.

This rapid development was made possible by leveraging the technology advancements achieved by ImPACT, Japan's national development program[1,2], and the proven technologies of the University of Tokyo's Hodoyoshi satellites[3]. These collaborations have enabled us to achieve both high-quality development and agile on-orbit demonstration. The balance between quality and demonstration speed is one of our leading principles for Synspective's development.

We currently acquire images based on customers’ requests and provide images to them. We have also established an emergency imaging system for disasters. In addition to our images providing business, we also connect our SAR data to Synspective's main business, solution services. The solutions that are currently available to the public include flood detection and land displacement. The future release of new services is being triggered by proof of concept projects with individual customers. At the moment, other SAR satellite data contribute to data sourcing, intending to progressively reduce the outside dependence as our systems evolve to fulfill high frequency services.

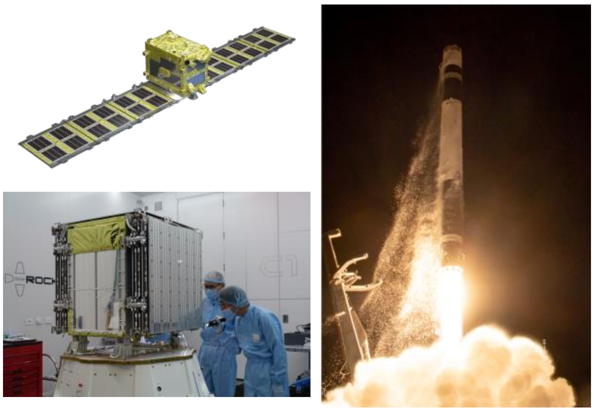

Figure. 1. StriX-α and its launch

(a) First image: South Florida

(b) Stranded ship at Suez

Figure. 2. Observed Images by StriX-α

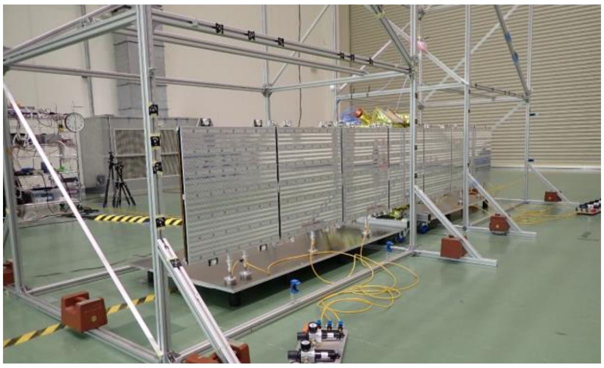

Figure 3 Successful deployment of the SAR antenna

The second satellite called StriX-β, the next demonstration satellite, is under development. Scheduled to be launched in the latter half of 2021, it is currently undergoing a test campaign. The main objective with this satellite is the demonstration of in-orbit InSAR (Interferometric SAR). It is equipped with thrusters and autonomous orbit control functions for this purpose. It is also equipped with a flexible mission computer to enable rapid functional expansion. A variety of experiments such as on-board deep learning, monitor camera operation, direct reception of data from ground sensors, and low-speed inter-satellite communication will be conducted using this system.

Figure 3. shows StriX-β after the SAR antenna deployment test, which is one of the critical events for the satellite testing schedule.

Synspective was founded in February 2018. The number of members has grown to over 100 coming from 18 countries, making up a truly multinational community. Seventy percent of the workforce contributes to solutions and sales activities, and thirty percent are in charge of satellite development.

CURRENT PLAN

Our SAR satellite features high resolution, wide area observation, high frequency observation, and observations under the same conditions. We will achieve a resolution under 1 m and a wide observation area over 20 km. In addition, by selecting a sun-synchronous daily revisit, we will achieve high frequency observations with the satellite constellation as well as observations of the same targets under the same conditions every day. Another important feature is the ability to conduct InSAR observation every day with the same satellite in the constellation. These daily and uniform observation conditions simplify data processing and enable the extraction of high-quality information. Of course, analysis with multiple satellite data from multiple observation angles is also possible.

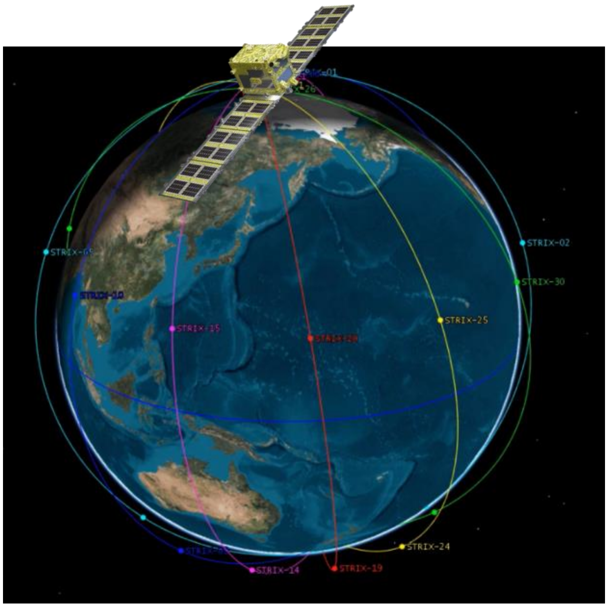

Figure. 4. Constellation Orbit

A constellation of six satellites is foreseen by 2023 and 30 satellites will be operating by the second half of the 2020 decade. This will enable us to observe regions of interest around the world within three hours.

StriX Series

The next satellite after StriX-β will be the precursor for the transition to full-scale multiple-unit production. While the basic design is inherited from the previous version, the functions that have been demonstrated so far, such as multi-target imaging capability and improved orbit control capability, have been enhanced. The procurement of onboard equipment has already started, and we are aiming to start assembly in the second half of 2021 and launch in the first half of 2022. The satellites up to this point are referred to as first-generation satellites.

The second-generation satellites will increase the observation area by expanding swath up to 35 km. The preliminary design and selection of onboard equipment are currently underway.

Studies have already begun for the third-generation satellite. Development is also underway to further improve the resolution and the addition of other functions.

Constellation

Figure 4 shows the orbit configuration of the 30 satellite constellation. It is a sun-synchronous orbit with a daily return at an altitude of 561 km. There are six orbital planes, and five satellites will be injected into each plane.

THE AUTONOMOUS SYSTEM ARCHITECTURE

Autonomy is essential for a multiple satellite constellation, especially important for the sake of agility by eliminating human interactions and decision-making processes and not only for a reduction in operation workload. We have three different perspectives of an autonomous system, not limited to the satellite system.

Operation

The first critical event in the operation of StriX-α is the deployment of the SAR antenna, which has a solar panel mounted on its back. After the satellite is separated from the launch vehicle, the SAR antenna will be deployed and pointed toward the sun to provide the necessary power and temperature stability. Unlike ordinary small satellites, we have decided to realize this sequence fully automatically.

The sequence worked perfectly as designed. After the de-tumbling of the separation rate, the SAR antenna was deployed. When we first checked the satellite status, we confirmed the SAR antenna had already been deployed and the satellite was stabilized. There was no task for the ground operator to stabilize the satellite conditions.

We continue working on the effort to automate the satellite operation and evaluation of on-orbit status with our machine learning technologies considering the future 30 satellite constellation.

Freshness of Data

To make the information service beneficial to society, the freshness of the information is important. For example, in the case of a disaster, there is a criticality on the reaction time in saving lives. It is important to understand the situation within a few hours and to make an action plan accordingly. Synspective develops autonomy with this entire information path in mind.

An experiment of direct reception of data from ground sensors at the second demonstration satellite, StriX-β, demonstrates the future autonomous operation of taking images based on the event detection by the ground sensors. It is rather difficult for a satellite to shorten the time from detection of the event to taking images of the affected area. We consider solving this issue with a system-level approach. We can have ground sensors with transmitters and the satellites can gather information from them. Information can be anything like water level, temperature, earthquake, and so on.

We will use store and forward functions demonstrated by the University of Tokyo[4]. The future satellite will observe the affected area with the ground sensor information and without any ground station contacts and operators' decision-making.

StriX-β has two edge computing devices for onboard deep learning and will demonstrate image processing capability. The devices are commercial-off-the-shelf products, and we confirmed their on-orbit survivability with a radiation test. These devices will enhance the freshness by processing the SAR data quickly on-orbit, transmit the extracted information to customers as same as we do on the ground, and finding events that lead the satellites to observe targets. With all these autonomous experiments, we pursue the freshness of data from the time an event occurs to the time it is delivered to the customer as the entire information path.

Building the system towards agile satellite development

Since Synspective is a company that mainly provides information services, the autonomous design aims to optimize the flow from information needs (not image needs) to satellite operations. We believe that an important challenge is to achieve application layer integration from a customer business system to a satellite on-board software through solution platform, data platform, satellite control ground system, and the satellite itself. We try to harmonize the software and information processes of the application layer, although the platform where the application is located, the organization where staffs belong and their culture are different. We treat this issue as part of the autonomous system architecture.

Within recent uncertain global circumstances, the need for satellite constellation changes in a matter of months. The development speed of a single satellite, including procurement of onboard equipment and its launch, is about 1.5 years and will be less than one year in the future. However, there will still be a gap between the speed of needs change and the speed of satellite development. In reality, frequent changes in decisions are made, although the original direction is based on close communication between the needs side and seeds side.

The changes are not necessarily caused by only negative reasons. There are times when it is important to be able to react quickly when an opportunity arises. Such a quick response to opportunities is a perspective that has not been commonly available in space development, which has been traditionally based on long-term plans. We will respond to both positive and negative situation changes by continuing to establish and develop a rapid decision-making system.

The current system highlights holding meetings regularly for identification of customer needs and reflect them in the satellite development. The first key thing is to recognize keywords of the needs side and seeds side and to have a common understanding of the interrelationships and constraints of important items. For example, the members' mutual understanding of the relationship between the region of interest of a particular customer, the orbit of the satellites, and the frequency and conditions of observation are typical and important.

By recognizing the relationship between the needs and the seeds, it will be possible to develop satellites effectively and also to develop needs that utilize the capabilities of small satellites without losing their limited capacity. For example, we can decide not to aim for global coverage, but to put satellites into the best orbit for a specific customer's region of interest, like putting a satellite into orbit with a daily return cycle.

Installing satellites into orbit with a daily return cycle means giving up global coverage of the observable area when the number of satellites is small. This means that we can only provide services to customers who are interested in a particular region. Choosing that orbit is a big decision if you do not know your needs or have not identified your customers. We decided to concentrate on the specific region of interest in the decision-making phase, as frequent and repeated observations under the same conditions are important.

Then, we consider new customer segments, based on the observable areas of the decided orbit. And we will consider a launch plan to install the satellites into orbit.

When we thoroughly understand the relationship between the needs and seeds, then we can design the autonomous decision-making system. In short term, the satellite and the ground system understand popular and attractive targets for customers, and the autonomous decision-making system will eliminate human interactions to select the observation targets. In the future, the factory will understand those attractive targets and manufacture an increasing number of satellites that match the selected targets and the orbit to observe them. This holistic autonomous system concept from the customer to the satellite manufacturing is one of the features of a company that has both solution department and satellite development department, which is the case of Synspective.

MULTI-SATELLITE PRODUCTIONS

To put a large number of satellites into orbit regularly, a system for multiple-unit production is necessary. We develop satellites, but also develop a system to manufacture and operate a large number of satellites in a short period.

We will achieve parallel production of 10 satellites by 2023. To achieve this goal, we have built a team of satellite experts and experts in aircraft, automobile, and other consumer electronics with 10~20 years of experience. We have collaboration with JAXA (Japan Aerospace Exploration Agency) and universities, as well as collaborations with a major automobile company, other space companies, to acquire technology, know-how, and human resources to develop satellites and build a system to produce multiple satellites.

The large SAR antenna, which is the characteristic of our SAR system is composed of seven foldable flat panels. It is lightweight, stiff, has few parts, and no electronics other than solar cells. Each panel can be manufactured and inspected independently. Therefore, it is good in quality stability, and the possibility of failure is small even on-orbit, contributing to the stable production and operation of many satellites.

Space development has always had a development process characterized by high quality. However, it was designed to ensure the success of an unprecedented one-off product on the first try. What is required of us is to 1) maintain the initial success rate to some extent and 2) increase the development speed. In addition, we can take advantage of multiple production opportunities. We will 3) use the experience of failure to improve quality without overestimating the experience of success, and 4) stabilize quality in the production of many satellites with the same design.

1) 2) and 3) 4) actually require different technologies and have different development processes: 1) 2) and sometimes 3) are mainly applied to the first satellite for each generation, while 3) 4) are applied to the production of multiple satellites within a generation.

1) 2) are similar to the conventional space development processes, although its processes are much lighter; 3) 4) are more manufacturing and test-focused processes that are tailored to the venture and its production scale, while utilizing the knowledge gained from the manufacturing of a large number of products such as automobiles and aircraft.

For the quality control system, we have established a system that utilizes the support and knowledge of the automotive industry.

FUTURE WORK

We will continue to develop new technologies and satellites, as well as build a system to develop multiple satellites. We will strengthen our core competence, the SAR technology, as well as attitude and orbit control technology, onboard software technology, thermal design and analysis technology, operation technology, multiple-satellite production technology, quality control technology, and project management technology.

In addition, the company will not only develop its current facilities in Japan but also strengthen its existing base in Singapore. We are also considering working with members in Europe and the United States.

We wish our activities contribute to our small satellite community or ecosystem and a system architecture including component suppliers, communication service providers, and data processing service providers.

CONCLUSION

We are developing small SAR satellites and will deploy a 30 satellite constellation by the second half of the 2020s.

We launched the first satellite in December 2020 and release images for customers. We are already preparing to build the following two satellites and preparing for the 2nd Generation satellites. Autonomy is essential for a multiple satellite constellation, especially important for the sake of agility by eliminating human interactions and decision-making processes and not only for a reduction in operation workload.

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