Automation and Labor-Saving Technology for Satellite Operation

GONAI Toshiya, INOMATA Sota

Abstract

NEC has been operating the high-precision compact radar satellite called ASNARO-2 since 2018, using GroundNEXTAR, a high-quality ground system package developed by NEC, to maintain stable operation. This paper introduces the features of the GroundNEXTAR and discusses what we have learned about automation and labor saving in the course of satellite operation. An important aspect of this is intention learning technology, a sophisticated form of machine learning that automates decision making by learning from experienced operators. With this technology, we can accelerate automation of satellite operation and reduce dependency on experienced operators for selection of observation candidates, a critical part of satellite operation.

Keywords

Earth observation satellite, optimization, decision making, artificial intelligence (AI), intention learning

1. Introduction

Successful operation of a satellite requires the active engagement of skilled operators who possess advanced knowledge and extensive experience. However, if we are to increase the effectiveness and utility of satellites going forward, we need to shift away from dependency on individual expertise. This is particularly true when it comes to operation of "satellite constellations" in which groups of satellites work together to provide simultaneous, uninterrupted global coverage. As the number of satellites that need to be operated simultaneously grows, so too will the need to automate the systems and minimize dependence on humans. Given this situation, we believe it is imperative to accelerate the automation of satellite operation systems and reduce the workload on operators.

At the same time, human decision making as to what should be done and how to achieve it cannot possibly be an objective of automation. Human intention is not a system output but rather a system input. Decision making relies heavily upon the experience and intuition of a skilled operator. But just as demand for these skills begins to accelerate, the pool of potential operators has begun to shrink due to the overall decline of the labor force. This leaves us with the problem of finding and training junior staff in order to pass on the necessary skills required to control satellite operations.

How, then, do we deal with this issue? One possible answer is to develop systems that can support and reinforce human decision making. NEC has been working towards this goal by automating routine tasks and using artificial intelligence (AI) — specifically intention learning — to automate decision making.

2. Overview of ASNARO-2

A high-precision compact radar satellite, ASNARO-2 was developed as part of a research and development project called Advanced Satellite with New System Architecture for Observation (ASNARO) under the auspices of Japan's Ministry of Economy, Trade and Industry (**Fig. 1**). The purpose of this project was to develop a small Earth observation satellite that would be competitive on the international market. Despite its small, lightweight design, this satellite incorporates powerful radar

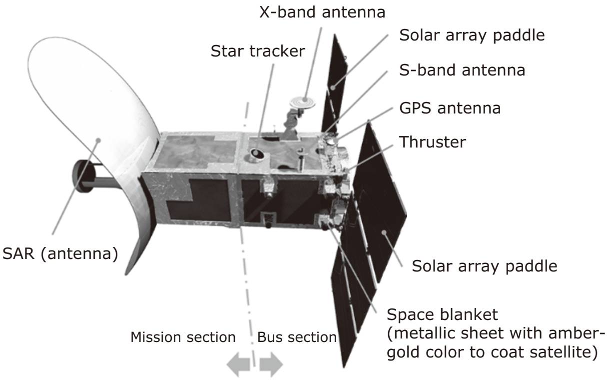

Fig. 1 External view of ASNARO-2.

Photo 2 NEC Satellite Operation Center (NSOC).

Photo 1 Image shot by ASNARO-2
(near container terminal, Sydney Harbour).

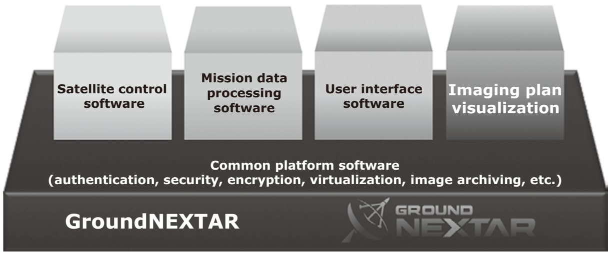

Fig. 2 System configuration of GroundNEXTAR.

(synthetic aperture radar [SAR]) technology that is not affected by the observation time zone or weather conditions and features high observation capabilities that can identify objects on the earth's surface smaller than 1 meter (**Photo 1**).

3. Features of GroundNEXTAR

To operate ASNARO-2, we developed the GroundNEXTAR ground system package and installed it at the NEC Satellite Operation Center (NSOC) (**Photo 2**). GroundNEXTAR is fully compliant with NEXTAR — NEC's standard compact satellite bus system for various space missions — and can also be used with other satellites.

Because conventional satellite operation systems are designed to work with specific satellites, they cannot easily be scaled up and offer limited flexibility. GroundNEXTAR is provided with the functions required for comprehensive operation of an Earth observation satellite, ranging from reception of observation requests, planning, satellite control and monitoring, image processing, and data collection, allowing it to be easily adapted to the specifications and operation requirements of each satellite (**Fig. 2**).

Among its many functions, GroundNEXTAR features two automated functions intended to reduce operator workload.

The first is an automatic command execution function. By preregistering tasks that need to be performed in the time zone where communication with the satellite is normally performed, the GroundNEXTAR features can be used to allow even operators without experience in satellite operation to safely monitor telemetry data and send commands to the satellite. Furthermore commands can be automatically executed even when operators are not available, thus helping to achieve labor saving in satellite operation.

The second function automatically adjusts the bus operation time to maintain the basic functions of the satellite. Bus operations for monitoring the status of the satellite are planned in coordination with the time zones in which mission operations are carried out for observation and downlinking data to Earth. Once a rough time schedule has been specified, GroundNEXTAR searches for the next available window when no other event is scheduled for implementation in that time zone.

4. What We Have Learned

ASNARO-2 was launched in January 2018, so we now have more than three years of experience operating GroundNEXTAR. We have learned a lot during that time. Three key insights stand out which can help lead to automation and labor saving.

The first is automatic selection of observation point candidates. The regions of interest to users who require satellite images change continuously depending on domestic and foreign circumstances, as well as unexpected events such as natural disasters, accidents, and so on. Automatic selection of observation point candidates makes it possible to observe new situations of interest and quickly provide images.

The second is automatic generation of observation requests. In ASNARO-2 operation, plans for Earth observation are made on a daily basis. Operators create observation requests that indicate when and where to image and draw up plans accordingly. Because these observation requests are created manually, they can occupy a significant portion of the operator's time, which means they might miss observation opportunities.

The third is automatic creation of operation plans. Plan creation involves a sequence of steps which include various tasks that GroundNEXTAR is equipped to automate. When plans can be created by simply inputting the tasks to be included, the operator's workload can be reduced at each stage of the process. Since routine tasks can be included, automation and labor saving of the system can be taken to an even higher level.

Out of the three key insights derived from our ongoing operation of ASNARO-2, we have zeroed in on the second one — automatic generation of observation requests — as being of particular importance. Using intention learning technology, we have been working to create a fast reliable system to automate this task.

5. Applying Intention Learning Technology to Task Creation

5.1 Intention learning technology

Intention learning is based on NEC's original inverse reinforcement learning technology.

Reinforcement learning searches for behaviors that maximize the selected objective function and learns a method (policy function, value function, etc.) for calculating the optimal behavior for each condition. Inverse reinforcement learning, as the name suggests, works in precisely the opposite way, learning the maximum optimization index from a history of behaviors (time series data of conditions and behaviors).

Intention learning can be applied to optimization of combinations — which was difficult to achieve with conventional inverse reinforcement learning technology. It also can learn (formulate) multiple optimization indices in a way that makes their intentions interpretable. Intention learning's applicability to combination optimization is especially valuable, potentially contributing to the automation of processes where humans conventionally determine an optimal solution based on certain standards.

Intention learning technology refreshes the features and weight of an optimal index while using the behavior history data of the designated expert as teaching data. Feature and weight are determined and the calculation is repeated as often as necessary so that the behavior history — which is uniquely calculated using the optimization solver (optimization AI) — comes as close to the expert's behavior history as possible. Through this process, it can learn which features the expert puts weight, thereby generating an optimization index that closely mimics the expert's behavior history. The optimization index can be expressed as a summation of the products of the weight and feature as shown in the formula below.

$$\text{(Optimization index)} = \sum_{i=1}^{n} w_i \times f_i$$

$$w_i\text{:weight}\quad f_i\text{:feature}$$

Intention learning technology can be applied in many ways — for example, scheduling shifts based on the skills of the employees and on their vacation requests or drawing up inventory plans that take supply and demand into consideration.

5.2 Creating observation requests

Given its capabilities, intention learning technology seemed ideally suited to automating the creation of observation requests (**Fig. 3**).

When generating an observation request from a vast number of observation candidates, the operator makes a comprehensive judgment while taking into consideration any limitations imposed by the satellite's design and any conflict between observation requests from different users. This process can be time-consuming and is further restricted by the number of operators available to perform this task. By having the AI learn the thought, or intention, that goes into selecting an observation candidate, it would be possible to optimize the combinations in which observation candidates are selected and to automate the creation of observation requests.

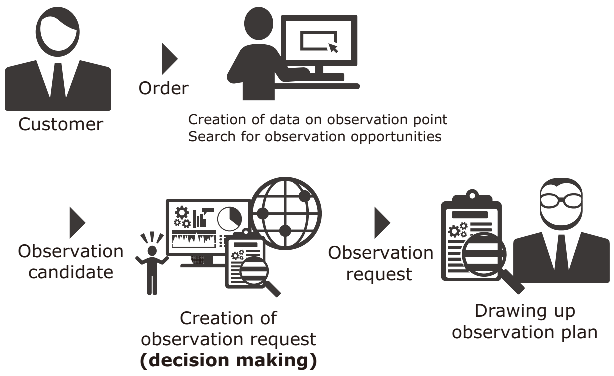

Fig. 3 Operation flow.

Table Considerations for observation request.

Feature	Viewpoint
Number of images	Need to shoot as many images as possible
Number of observation points	Need to shoot as many points as possible
Shooting angle*	Need to shoot at angle in specified range
Priority	Need to start with orders from higher-priority users

* Radar incidence angle of SAR (off-nadir angle)

We have formulated an optimization index based on four key points.

$$\text{(Optimization index)} = w_1 f_1 + w_2 f_2 + w_3 f_3 + w_4 f_4$$

f_1:number of images, f_2:number of observation points, f_3:shooting angle, f_4:priority

An experienced operator creates an observation request from the viewpoint shown in **Table**.

We had the AI use the expert's behavior history to repeatedly calculate the weight of each feature used in the creation of observation requests as teaching data for the intention learning engine.

The results of the above approach were excellent.

- Reproduction of an experienced operator's intention at high precision: 94% reproduction accuracy
- Reduction of time required for a task: Reduced to 1/6 — from 120 minutes (average time required by an experienced operator) to 20 minutes (even when performed by an inexperienced operator)

6. Conclusion

At NEC, our focus is always on improving the functionality and performance of our technology. This is especially true of our satellite operation systems. Our experience in operating ASNARO-2 has taught us much about how and where to implement automation and labor saving in satellite operation. The application of intention learning technology to creation of observation requests in GroundNEXTAR has achieved remarkable results and we are firmly committed to applying this knowledge to the development of future satellite operation systems. We are confident that this technology can be applied to similar systems designed to meet demand from multiple customers with limited resources. Through the automation of satellite operation systems and the development of other AI-based automation and labor-saving technology in the years to come, we will continue to provide a solid foundation that will sustain the values that shape modern society.

Authors' Profiles

GONAI Toshiya
National Security Solutions Division

INOMATA Sota
Assistant Manager
Network Infrastructure Business Unit
NEC Networks & System Integration Corporation

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