Fundamental Space-Supporting Technologies and Their Development Process

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Abstract

NEC's space technologies are supported by a broad range of fundamental technologies. Production innovation activities have brought space technology from a field of work dependent on the skills and techniques of expert workers to the forefront of production innovation. Space technology is inextricably linked to material development. NEC developed the most advanced reaction-sintered SiC optical mirror material, which makes it possible to manufacture a mirror with light weight and high strength. Meanwhile, spacecraft on-board software technology is being developed to meet the trends of diversification and increased precision of mission requirements. Image processing for more advanced utilization of remote sensing data is a technology that responds directly to the needs of data users. This paper introduces the above fundamental technologies supporting NEC's space technologies and their development process.

Keywords

TPS, production innovation activities, solar array panel, optical mirror, material, SiC, spacecraft on-board software, high reliability, mission diversification, development process, image processing

1. Introduction

To develop equipment and systems for space use and to provide associated services, it is indispensable for us to possess a very broad base of fundamental technologies. In this paper, we will introduce our production innovation activities, our mirror material technology which is a core sensor technology, our software supporting all systems and our image processing technology which is the key to the utilization of data.

2. Production Innovation Activities

2.1 Background

We at NEC have been involved in a large variety of space equipment and systems, such as the MUSES-C (HAYABUSA), which demonstrated the height of Japanese and NEC technologies worldwide, and the IKAROS, which is continuing its solar sailing using the radiation pressure of solar light as its propulsion force. Although these spacecraft achieved great results from the viewpoint of accomplishing their missions, it is also a fact that much of this work is dependent on the skills and techniques of expert workers from the viewpoint of the "MONOZUKURI" [*1] process, from development/design through to production/testing.

Recognizing that it is urgent for an enterprise in charge of "MONOZUKURI" to solve the above problem as early as possible, we first proceeded to production innovation activities at the site of commercial solar array panel production.

2.2 Start of Activities with Solar Array Panels for Commercial Satellites

The initial process of the production of the solar array is CICing. [*2] In the case of the commercial satellite, more than 2000 CICs is assembled for one panel. CICs are connected in series by welding machine and then bonded onto the light weight substrate with adhesive (**Fig. 1**).

We began our innovation with the "2S" methodology of

[*1] "MONOZUKURI" is a Japanese word meaning production; "MONOZUKURI" in this paper covers a value chain including product development/design, production/testing and delivery processes.

[*2] CIC: Coverglass Integrated Solar Cell.

sorting (SEIRI) and setting in order straightening (SEITON) using the red tag technique *3 and followed this with a thorough application of the "3-fixed" methodology (fixed location, fixed items and fixed quantity) and advanced synchronization of the rough flow by preparing a VSM *4 . Here, "flow" refers to "a train of items that move regularly (tactically) according to the progress of the process." Based on the results of our work analysis, we focused on 1) advancing workload leveling; 2) changing to a layout with a good view (see **Fig. 2**); 3) determining the takt time; 4) conducting process observation. In this series of activities, we were able to view our efforts from the viewpoint of total optimization.

After efforts at the site of production of solar array panels, our production innovation activities have now extended to the site of production of satellite-borne equipment. After the application of the "2S" and "3-fixed" methodologies, layout change activity for the creation of rough flow is underway, and activities are also promoted in the model line aiming at increasing production quantity by shortening production lead time.

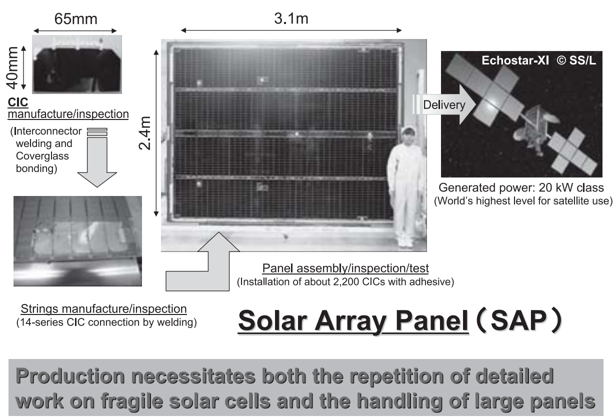

Fig. 1 Outline of commercial solar array panel production.

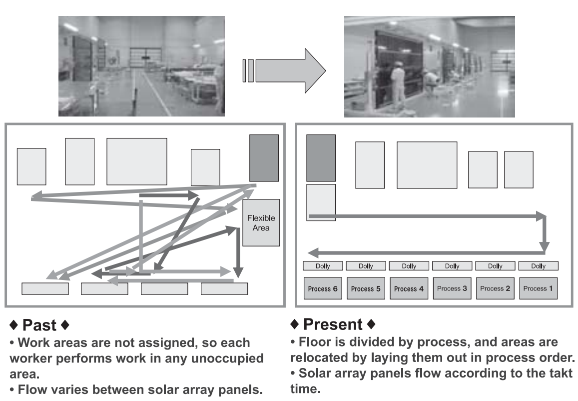

Fig. 2 Creation of flow.

2.3 Satellite Standardization and Company-wide Process Improvement

In the development and design department, efforts for standardizing small satellites with the NEXTAR (NEC Next Generation Star) bus are underway. With the NEXTAR bus, we are standardizing bus components equipped with universal basic functions and are combining various mission components in order to conduct business in the global market by taking advantage of the benefits of standardization, including low costs, short delivery terms, high flexibility and reduced risk.

By promoting this effort for standardization in combination with production innovation activities, we are also improving the entire process of "MONOZUKURI" at the top level, from development and design to production and delivery.

2.4 Future Perspectives

To make the space business profitable, it is necessary to implement world-class QCD (Quality, Cost, Delivery) early. Although we are still at the entrance to "product innovation," we are determined to advance our activities as "one NEC" aiming at total optimization in order to foster human resources capable of performing autonomous reform as well as management innovation.

3. Mirror Base Material Development Technology

3.1 Satellite-borne Optical Mirrors

Satellite-borne optical sensors must improve spatial resolution to acquire more detailed information. For this purpose, large-aperture reflector optics are adopted to improve sensitivity with increased amounts of light and to enable the observation of fine spatial structures.

*3 Red tag technique: A technique for classifying necessary and unnecessary items by attaching warning tags (red tags) and disposing of unnecessary ones.

*4 VSM: Value Stream Map (mapping of material and information flow).

On the other hand, a large optical mirror needs to minimize the surface distortion caused by its own weight and must feature light weight, high strength and high rigidity in order to withstand the severe vibration and shock load of the rocket launch environment. In addition, thermal shape stability is needed to deal with temperature changes in the orbital environment.

3.2 SiC ceramic material

Compared to glass, the traditional mirror base material, SiC (silicon carbide) has high thermal stability because of a relatively low thermal expansion coefficient, high thermal conductivity, high strength and high rigidity. **Fig. 3** shows a performance comparison between glass and SiC. Thanks to these properties, SiC has recently been put to practical use in overseas countries as the base material for high-precision mirrors larger than 1 meter and in 3.5-meter cooled IR optics.

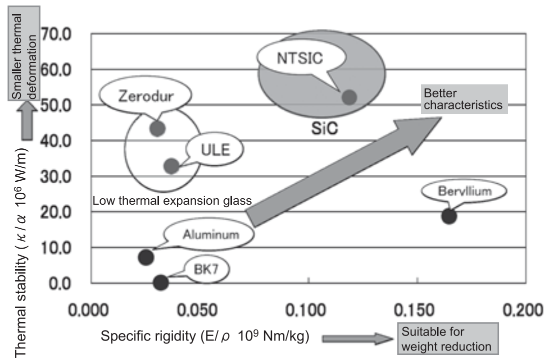

Fig. 3 Comparison of Mirror Base Materials

3.3 New–Technology SiC (NTSIC)

NEC is developing and marketing a high-strength, reaction-sintered SiC material under the product name "New-Technology SiC" (NTSIC). This high-strength, reaction-sintered SiC material is developed by combining technologies of exclusively Japanese manufacturers [*5] .

1) Pore-free, dense construction

In the NTSIC manufacturing process, silicon is infiltrated during sintering so that the carbon in the material powder reacts with the silicon to become SiC. At this time, residual silicon fills the remaining pores, and a fully dense of sintered body is obtained. With conventional sintered SiC, the surface is coarse due to the presence of pores, as shown in the left picture in **Photo** , or polishing is difficult because of non-uniformity due to the presence of constituents other than SiC, thereby making it necessary to coat the mirror surface with SiC before polishing it. With NTSIC, on the other hand, the consistency is dense, as shown in the right picture in the photo below, so the shape and surface roughness required for the mirror surface can be obtained by polishing the surface directly. Avoiding the need to coat before polishing can reduce cost and lead time.

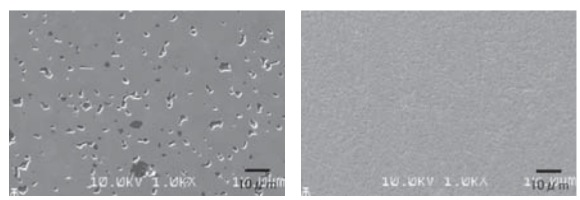

Photo Photomicrographs of polished surfaces: Sintered SiC (Left) and NTSIC (Right).

2) High strength

With a bending strength twice that of conventional sintered SiC and more than 15 times that of glass, NTSIC has excellent properties for use as the base material of a large mirror with reduced weight. Taking the main mirror of the Hubble Space Telescope (diameter 2.4 m, weight 828 kg) as an example, the use of NTSIC would make it possible to reduce mirror weight by more than 600 kg.

3.4 Future perspectives

NTSIC has begun to be used as the mirror base material for various optical sensors, including that of the ASNARO (Advanced Satellite with New system ARchitecture for Observation) currently under development. We are also tackling research into bonding mirror segments to produce larger reflectors and into reducing the structure's thickness to reduce weight further, aiming at differentiating our technologies as fundamental technologies unique to NEC.

*5 This technology is based on a joint development project with the Power and Industrial Systems R&D Center, Toshiba Corporation Power Systems Company and Japan Fine Ceramics Co., Ltd.

4. Large-scale Software Development

4.1 Background

The trends of diversification and increasing precision of mission requirements for spacecraft have promoted increases in the complexity and scale of software, which have led to problems such as the impossibility of taking enough time for software verification. The following subsections introduce the fundamental technologies we are tackling for the development of complicated, large-scale software programs.

4.2 Fundamental Technologies for Large-scale Software Development

Spacecraft on-board software is subject to severe quality requirements because of the restrictions that incorrect execution cannot be permitted in orbit and modification is not easy. The fundamental technologies targeting the development of large-scale software programs and their development processes are described as follows:

(1) Use of RTOS

Since the incorporation into computers of 16-bit MPUs, we have been using an RTOS (Real-Time Operating System) with the μITRON specification.

Even today, as MPUs have advanced to use 64 bits, we still use an RTOS based on the TOPPERS and T-Engine kernels, in consideration of a smooth transition to the development of large-scale software.

(2) Middleware

64-bit MPUs are making processor handling more difficult than it was before. Since the main work of executing spacecraft missions is concentrated in application programs, we prepare the work for direct hardware control separately from the application programs and attempt to make it a common component. This concept has been in use for a long time, but it is still effective for expanding the use and range of application programs and for facilitating the development of large-scale software.

(3) Development process

As increases in the scale and complexity of software have been extending the time needed to obtain system requirements and to establish software requirement specifications, the traditional waterfall development model is not capable of reserving enough time for software development. To deal with this problem, we have adopted repetitive development, which handles the cycle from subsystem (or sensor system or component) requirement analysis to subsystem testing including software development process. This has made us able to deal with complicated requirements and the long time before they are established. We are also reviewing the development process so that it can reflect the results of repeated cycles (**Fig. 4**).

In the requirement analysis process, we are newly promoting examination of the operating scenario by incorporating the utilization requirements of the spacecraft system, sensor system, etc. Implementing each and every function required from the user's point of view is expected to enable the development of high-quality software.

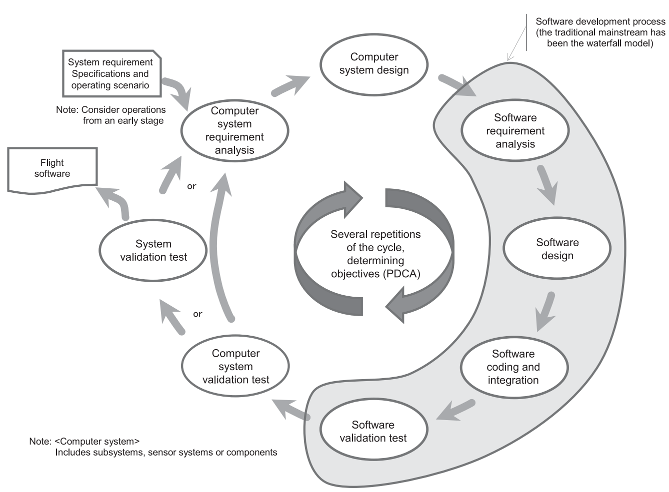

Fig. 4 Review of the development process.

4.3 Future perspectives

With large-scale software development, we aim to develop high-quality software by utilizing already-developed software, freeing ourselves from consciousness of hardware (processors), reviewing the traditional development process and reviewing the upper process rather than following the traditional method of entrusting the entire process to a highly skilled expert. The small satellite currently under development is being developed based on these concepts.

5. Image Processing Technology

5.1 The Role of Image Processing

The image data acquired by Earth observation satellites and other satellites is passed through several systems and finally delivered to data users. The important points for data users are as follows:

(1) A sufficient amount of data should be provided.
(2) High-quality data should be provided.
(3) Data matching users' needs should be provided.

At NEC, we are striving to improve the satisfaction of data users by applying unique image processing technologies at various stages up to the point that data is delivered to the user. The following subsections will describe optical image compression, image correction (level 1 processing) and higher-level processing. For the processing of SAR images, please read the paper entitled "SAR Image Processing Technologies are Improving Remote Sensing Data."

5.2 Image Compression

Before a satellite transmits the image data it has captured, it compresses the data in order to transmit a larger amount of data within a limited data transmission capacity. StarPixel is a NEC-original image compression method that is capable of quick compression thanks to fewer calculations than JPEG2000 while achieving a compression rate almost equivalent to that of JPEG2000. Its high processing speed allows it to be processed with software without developing a dedicated LSI as is required with JPEG2000. StarPixel has already been used in satellites, including the PLANET-C (AKATSUKI) Venus climate orbiter.

5.3 Image Correction (Level 1 Processing)

Image data captured by satellites is not easy to use as-is, due to noise (such as stripes due to sensitivity deviation between pixels) or geometric distortion. Image correction processing is applied to such images to reduce noise and to apply geometric correction so that the image can be superimposed on a map, etc. We have been in charge of image correction for several satellites, including the ADEOS (MIDORI) and ALOS (DAICHI), and have contributed to the generation of high-quality images thanks to high-precision correction. We at NEC have also been in charge of image correction for atmosphere sensors, such as one used by the GOSAT (IBUKI).

5.4 Higher–level Image Processing

It is not always simple images that data users need. They also sometimes need the data obtained through image processing (called higher-level data), and one of the types of higher-level data provided by us at NEC is 3D data. **Fig. 5** shows an example of 3D topography produced from the PRISM images of the ALOS (DAICHI). [1] 3D data is particularly useful for users who want to produce maps.

Fig. 6 shows a 3D model of Asteroid 25143 ITOKAWA developed from images captured by the asteroid probe MUSES-C (HAYABUSA). [2]

5.5 Future perspectives

R&D into image processing technologies is conducted in various NEC departments, including the Central Research Laboratories. Based on collaborations between departments, we will offer users satisfactory image data by enhancing technological capabilities.

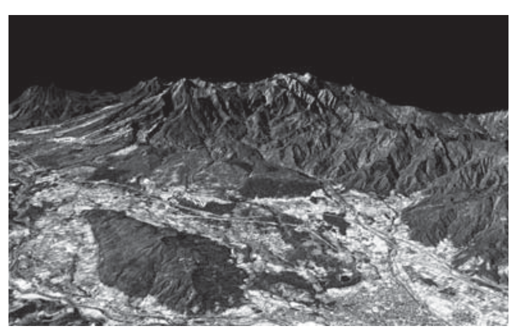

Fig. 5 Example of higher-level data (3D topography).

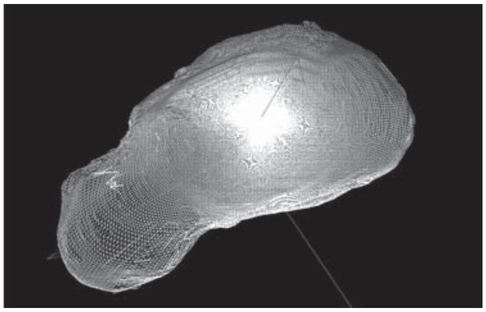

Fig. 6 Example of higher-level data (3D model of Asteroid 25143 ITOKAWA).

6. Conclusion

In the above, we introduced some of the broad range of fundamental technologies supporting NEC's space technologies. We believe that the organic combination of these technologies, along with other fundamental technologies that we were not able to introduce herein due to the limited space, led projects such as the MUSES-C (HAYABUSA) mission to successful results. In the future, we are determined to advance development and innovation continually.

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Vol.6 No.1 Space Systems

Vol.6 No.1
April, 2011

Special Issue TOP