# Achievements of Space Debris Observation

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**Over the years, Fujitsu has been working with the Japan Aerospace Exploration Agency (JAXA) to develop and operate JAXA's system for observing space debris, and helping with its data processing and orbit analysis. There is a risk that space debris could collide with artificial satellites or hit the Earth's ground. Thus, JAXA has been tracking the orbital courses of debris using data from optical telescopes and radar observatories. Furthermore, the orbital data are used to monitor pieces of debris that approach satellites, and to calculate their re-entry into the atmosphere. Fujitsu has been supporting this endeavor through technological engineering and system development. We have developed a high-precision orbit calculation technology to track pieces of orbiting debris, monitor their approach to satellites, and provide analysis and forecast their re-entry into the atmosphere. Also, with enhanced space debris observation and technology to optimize observation plans, we have succeeded in making orbit tracking more efficient with fewer ground stations. As for the system development, we have striven to ensure higher computational accuracy in orbit calculation and analysis, developing a parallel computation system and automation in order to process a vast amount of data in a short time. This paper explains the structure and features of this system, developed for managing and analyzing space debris. It also describes the specific technologies applied in major observational tasks, and their results.**

## 1. Introduction

Space debris is increasingly becoming an international challenge. Space debris is human-made waste material that floats in space, caused by events such as the breakup of a rocket, or the remains of disused satellites or fragments of satellites produced in an explosion or collision.

Space debris in a low orbit moves at a speed of more than 7 km/s around the Earth. Even a small piece of space debris is powerful enough to cause damage to the International Space Station and satellites. Moreover, a collision with satellites creates even more space debris. The number of pieces of space debris is on the increase. According to Space-Track.org,[1] a website run by the U.S. Department of Defense's Joint Space Operation Center (JSpOC), there are more than 17,000 pieces of space debris today that are larger than 10 cm in diameter (**Figure 1**). Furthermore, the pieces of debris that are moving at a relatively low altitude are gradually pulled into the atmosphere by gravity, and there is a risk that larger pieces that re-enter may pass through the atmosphere without completely burning up, and reach the Earth's surface.

In Japan, the "Basic Plan on Space Policy"[2] addresses the importance of preserving the space environment and the need for better capabilities to observe space debris. It also recognizes that international cooperation and contributions in this area are much needed. Meanwhile, observational facilities and equipment for data processing have been developed since the 1990s as part of a national effort to develop and improve technologies for space debris observation and analysis.

Since FY1995, Fujitsu has been developing a system to manage the orbital data of space debris, and a simulation system to analyze its re-entry into the atmosphere based on the orbital data thus obtained. This project was commissioned by the Japan Aerospace Exploration Agency (JAXA; former National Space Development Agency of Japan). Fujitsu is a starting

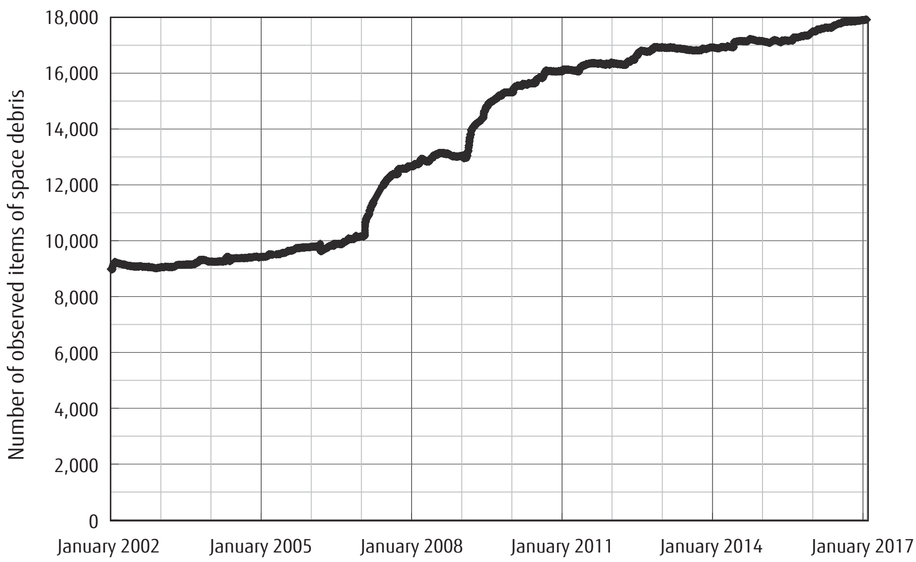



**Figure 1**
**Number of pieces of space debris over time (including satellites).**

member of the system development. We linked up with the optical telescopes and radar observatories owned by the Japan Space Forum (JSF) to process the observational data and analyze the orbits.[3] We have established technologies for observation/analysis through these experimental operations, working constantly to enhance and improve the system's features.

This paper first explains the configuration and features of this system, developed for observing and analyzing space debris. It also gives some descriptions of the tasks involved in the planning of observations and measurements of space debris, conjunction monitoring, and re-entry prediction analysis that leverage this system, highlighting the achievements made by the applied technology.

## 2. System configuration

The space debris management/analysis system acquires data for use in orbit simulation from optical telescopes and radar observatories, based on the observational plans the system sends out to them. Also, there is a configuration to acquire satellite orbital information from a system managing the orbits of satellites, and to acquire orbit information on space debris from Space-Track.org (**Figure 2**).

In order to execute and process large-scale computations in a short period of time, the system is equipped with the following four server groups, and each of them has unique functions (**Figure 3**).

1) Database (DB) server

This server stores the orbital information and analytical results concerning space debris. The accumulated data serve as the basis for detailed historical analysis of the orbital in formation of space debris.

2) Processing server

This server performs a large volume of orbit simulations and analysis for space debris in a short period of time. To this end, it adopts a parallel processing system, where computations are executed on several computers simultaneously.

3) Task control server

This server is responsible for automating daily tasks, such as orbit calculations and conjunction assessment. It also ensures that jobs are equally distributed among several computers, and redistributed in the case of a computer malfunction.

4) Application server

This server is the platform on which users can run analyses using the orbital information and other data.

## 3. Feature configuration

The system has the following features for processing data of space debris observation, and analyzing its courses.

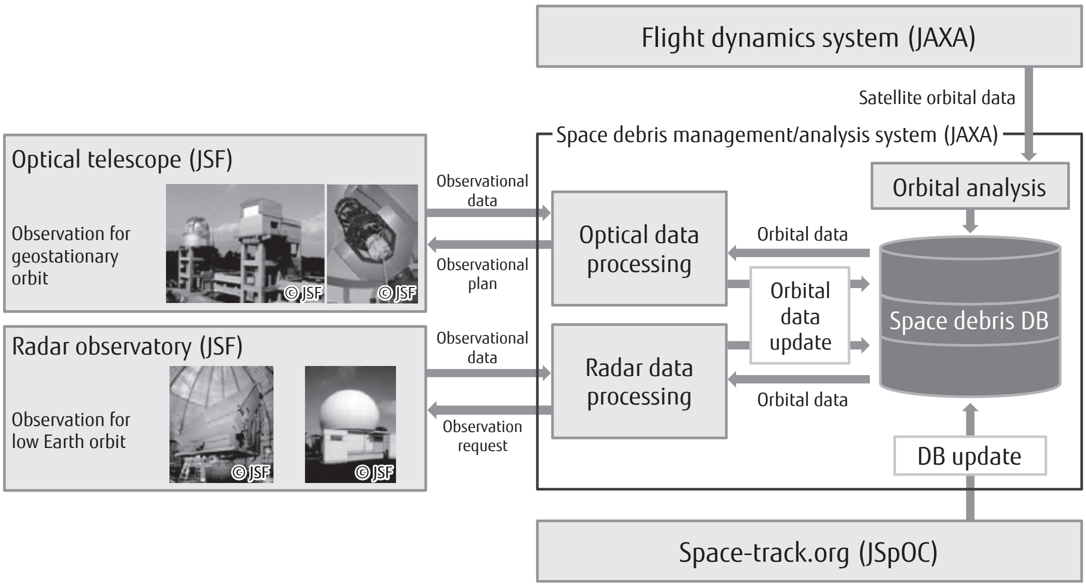



**Figure 2**
**Configuration of the space debris management/analysis system, observation stations, and relevant systems.**

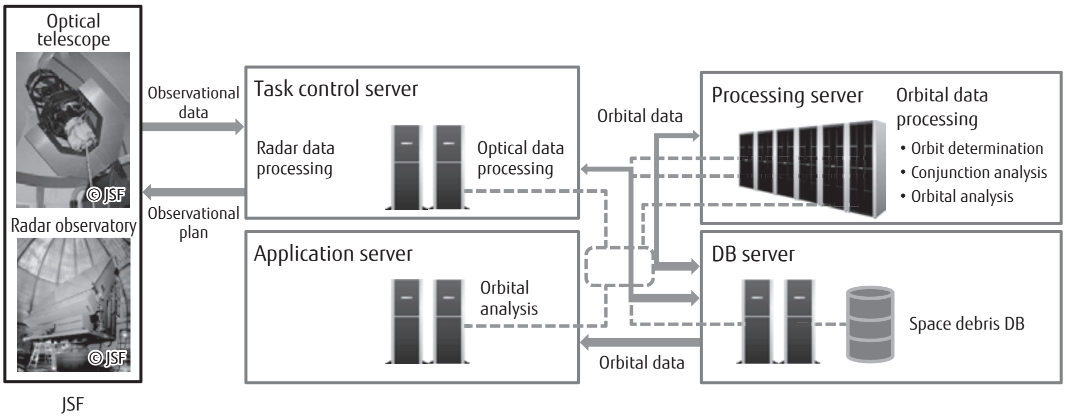



**Figure 3**
**Configuration of system to manage and analyze space debris.**

1) Preparation of observational plans

It identifies the target debris and observation periods and prepares an observation plan. This plan is then sent to observatories together with details such as start/end time and direction to be observed.

2) Orbit determination

Orbit determination is a computational process to determine the orbit of space debris based on observational data. The orbit thus acquired is used in the subsequent observational plans. It is also used for the following conjunction assessment and re-entry prediction analysis.

3) Conjunction analysis

This feature uses the orbital data for space debris and satellites to predict conjunction of space debris to satellites.[4] Predictions are executed regularly, and the results are automatically distributed to the relevant sections. The information on satellite orbits is obtained online from the system that operates them, which allows the prediction to use the latest orbital calculations that subsequent orbital control plans.

4) Re-entry prediction and analysis for space debris

This feature calculates the date, time, and point of debris' re-entry into the atmosphere. It can make a prediction for a variety of orbits, from imminent re-entries to ones in several decades' time.

## 4. System operation

We operate the aforementioned system to ensure four features: plans on space debris observation, orbit determination, conjunction monitoring, and re-entry prediction analysis.

1) Orbital data on space debris obtained through radar/optical observation

The orbital data of space debris are obtained by orbit determination using observed data sent from observation stations based on observation plans.

The radar observatory is used to monitor space debris in a low orbit. For space debris floating in a geostationary orbit at an altitude of 36,000 km, optical telescopes are employed.

2) Conjunction monitoring of space debris to LEO satellites using radar observatory

The conjunction assessment of space debris to LEO satellites is conducted based on the orbital data for satellites and space debris. The analysis can give the expected approach time and distance between them and visualize the results (**Figure 4**). While a piece of space debris is approaching a satellite, observation and conjunction prediction and analyses are conducted repeatedly. If there is a high possibility that a predicted collision will occur, the satellite course will be changed to avoid any possible collisions with the space debris.

3) Re-entry prediction and analysis for space debris using radar observatory

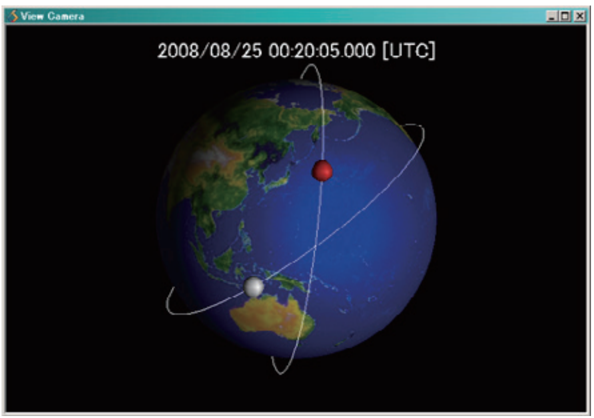
This mainly focuses on the space debris that originated from JAXA's terminated satellites and rocket bodies, as well as the debris that may fall in Japan. The analysis returns the predicted time and location of debris re-entries.

One major factor that may affect the accuracy of re-entry prediction is air drag. The density of the air is greater at lower altitudes. As the space debris experiences greater drag, it loses its velocity and the effect of gravity becomes relatively larger, then it heads toward the ground more rapidly. Calculations of the air drag significantly affect orbital calculations for space debris, in terms of the accuracy of the predicted time and location of re-entry. The drag varies depending on the debris' rotation state as well as on fluctuations in the air density due to solar activity and geomagnetic variation. These phenomena are difficult to predict with accuracy. As a result, a large error may occur in the prediction of the re-entry time and location. The system computes the error itself, and indicates the error range for the re-entry location (**Figure 5**).

In order to reduce the error in re-entry prediction, frequent observations for space debris are applied to update predictions. By calculating the latest orbit of the space debris at the re-entry time, the error of the prediction of the orbit can be reduced. The radar observatory can repeat observations daily or twice a day to predict the re-entry of relatively large space debris. Thus, observation and calculation are conducted repeatedly until the debris re-enters the atmosphere.

4) Conjunction monitoring of space debris to geostationary satellites using optical telescope

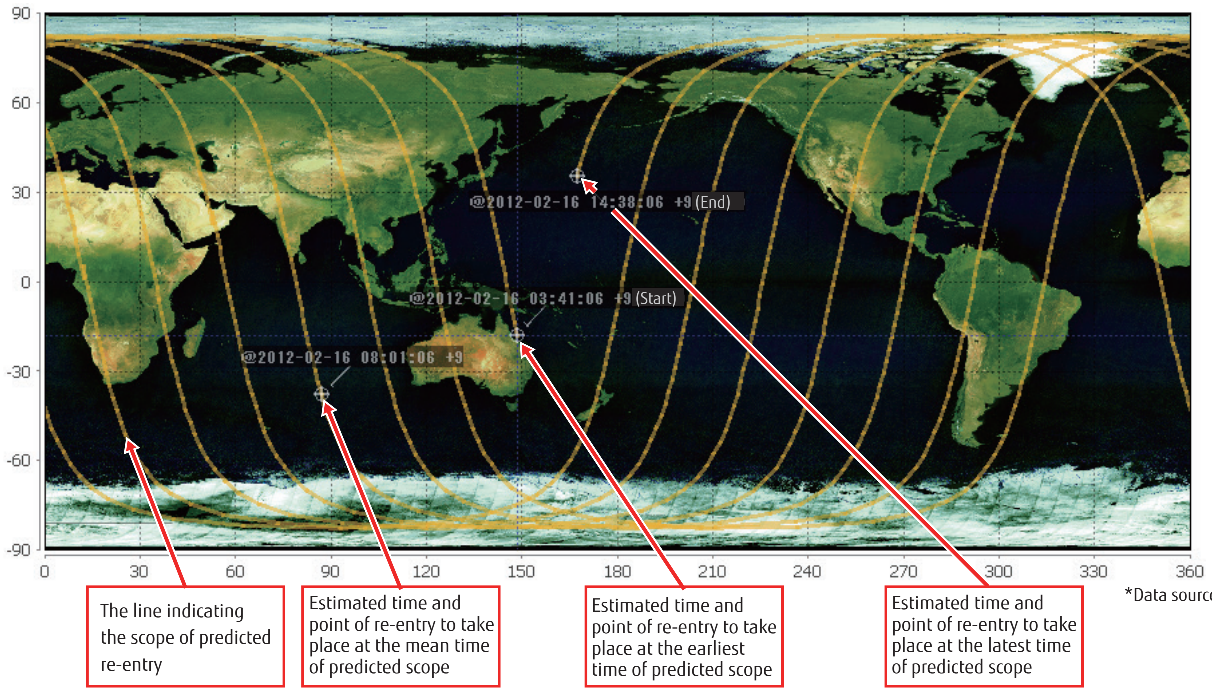
Optical observations are conducted during the night-time in order to clearly see the solar light reflected on space debris. The observations are subject to the weather, as a cloudy sky may block out such reflected light. For this reason, we organize and commence observations of space debris approaching geostationary satellites well in advance, approximately three weeks before the predicted conjunction time. In the observation, errors of orbit predictions both for space debris




*Data source: JAXA

Orbits (lines) and positions (spheres) of the satellites and space debris are depicted. In addition to the real-time rendering, a moving image from the past to the future can be displayed.

**Figure 4**
**Visualization of converging orbits.**




*Data source: JAXA

**Figure 5**
**Error margin of the point of re-entry prediction.**

and geostationary satellites are considered to identify those items which are likely to see a conjunction.

While the debris is approaching the satellites, observation and conjunction assessment are conducted repeatedly. If a collision is predicted to be highly likely, the satellite orbit will be changed to avoid a collision. This is exactly the same as in the case of LEO satellites.

5) Determination of space debris and its orbit determination using optical observation

In optical observation, detection of new space debris, mainly in a region, is also part of the operation. These new pieces of space debris are not found on Space-Track.org website. Thus, it is very important to identify new space debris in order to reduce the risk of collision with satellites.

6) Conjunction monitoring of space debris to protect the H-II Transfer Vehicle KOUNOTORI

KOUNOTORI is an H-II Transfer Vehicle (HTV), used to transport materials to the International Space Station. Therefore, it is crucial that the ship avoids colliding with space debris.

A final decision for KOUNOTORI to avoid collision with space debris is made based on highly accurate analysis on the orbit of space debris conducted by the U.S. By comparison, this monitoring aims to promptly detect any risk of conjunction with space debris, and we can analyze the risk in a shorter period of time than our U.S. counterpart, using the orbital information accessible on Space-Track.org website. An early detection will give us enough time to prepare for any necessary course changes in order to avoid collisions.

7) Emergency observation and orbit tracking during satellites' emergencies

Large satellites usually have a system to communicate with ground stations to give precise orbital information. In the case of a failure in the telecommunication system due to faults in the satellite, however, it becomes impossible to obtain that information. In such a case, a radar observatory and/or optical telescopes are used to track the satellite orbit. The orbital data thus obtained are fed into the system to manage the satellite orbits, and used to assist in satellite recovery efforts.

## 5. Technological innovations

There are mainly three technologies established from the above undertakings: orbital calculation technology, technology to improve accuracy of observation, and technology to optimize plans for observation. Each of them is described below.

1) Orbital calculation technology

In order to determine the orbit of space debris, it is crucial to calculate its orbit precisely. We employed appropriate mechanics models such as gravity and air density models, and applied some corrections like aberration of light and refraction to the characteristics of radar/optical observations, to ensure sufficient accuracy of orbit calculation.

In terms of optical observation, we obtained the orbital data for the quasi-zenith satellite-1 MICHIBIKI (at an altitude of about 36,000 km), and the resulting error (root mean square error or RMSE) of position was 0.95 km.[5] As for radar observation, we obtained orbital data for the Advanced Land Observing Satellite DAICHI (at an altitude of about 690 km) to evaluate the accuracy of the observation, and the resulting RMSE of position was 0.037 km.[6] These results are about equal to the accuracy of radar and optical observation data. Although the optical and radar observations have only one observation point each, they both achieve accurate orbital calculation.

The orbital calculation is also used for debris conjunction and re-entry prediction analysis of space debris. Re-entry prediction analysis is especially affected by the uncertainty of air drag, resulting in a large error. We verified the justification of the error by comparing data with prediction results provided by overseas institutions. As a result, we confirmed that the accuracy of the re-entry prediction was close to that provided by overseas institutions with several radar observational stations, although there were few opportunities for observation (because there was only one station) and so the amount of data obtained was smaller.[7]

Furthermore, the system is able to calculate the past orbital data of space debris that has been discovered using the present observation data, and identify the original object which generated the debris as well as the estimated time when the debris was generated. In fact, it has successfully identified in one case that newly discovered space debris was generated by an accident in which a rocket crashed 20 years ago.[8]

2) Technology to enhance accuracy of observation

It is difficult to observe space debris in cases such as when there is extremely small debris and a large error involved in orbital predictions. We have improved the chance of successfully observing small space debris by establishing a method to select the best distance to start the radar acquisition and the best scanning mode.[9]

As for the issue of a large orbit error, we have established a method for observation that takes into consideration the errors.[10] In this method, we first analyze the latest orbital data to look for any changes and understand the extent of errors. Subsequently, observations are consecutively executed in several directions which arise from the variation of the orbit error. The orbit error is greater at lower altitudes, where the air drag is uncertain. Thus, if the debris is close to re-entering the atmosphere, the error becomes noticeably large. By applying this method, we can successfully observe space debris that is large enough to be acquired by radar observatories, even immediately before its re-entry into the atmosphere.

3) Technology to optimize plans for observation

Efficient planning is essential to ensure highly accurate orbital observations of space debris as much as possible. To this end, we need to identify which debris to observe, for how long, and at what timing.

Regarding the aforementioned conjunction monitoring between a geostationary satellite and space debris, we have established a method to consider the errors involved in the planning of observations for both geostationary satellites and space debris,[5] and usually the observation is started three weeks before the predicted conjunction. For cases in which the purpose of observation is just to track the orbit at certain intervals, we have devised a method of carrying out infrequent orbit tracking (once a year) by accepting the error in orbital prediction to the extent that we do not lose track of the debris.

As stated above, we have managed to realize both conjunction monitoring and orbital tracking with only one point of optical observation.

## 6. Future challenges

JAXA plans to improve the observational performance of its radar observatories and optical telescopes. If it is realized, the number of trackable space debris is expected to increase. This would necessitate further enhancement of data processing systems in terms of the following features and performance.

1) Improvement of efficiency in observation

The observational planning features will be improved in order to achieve more observations of space debris and orbital tracking. Leveraging innovative technologies, automatic parameter tuning for a greater success rate in observations will be also established.

2) Improvement of technology to identify the observed object

Identification technology and its automation that identify which space debris is the observed object will be established. To realize appropriate identification, detection and estimation technologies of orbital alterations of satellites will be also developed.

3) Capability to process large volumes of data

A high data processing performance will be required to handle the larger volume of data generated in orbital calculation, conjunction prediction and analysis, and re-entry prediction analyses as the number of observations increases. To improve the speed of conjunction detection, automatic processing will be enhanced and the timing of data processing will be enhanced in order to recognize the status of conjunction in a timely manner.

## 7. Conclusion

This paper described data processing and orbital analysis in space debris observations, focusing on the system that we developed, the tasks pursued, and the technologies applied to the observations. Fujitsu has made technological enhancement in space debris observation with orbital calculations, conjunction prediction, and re-entry prediction analyses, helping to achieve and improve the tasks at hand. We will continue striving to improve our technologies and to enhance the work and system.

We would like to express our deepest appreciation to the members of the JAXA Space Tracking and Communications Center for their dedicated cooperation in developing and operating the system.

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