Asteroid Explorer “HAYABUSA” Rescue Operation

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Abstract
The communication link to Hayabusa was lost at December 8th, 2005. This is believed to be caused by the leakage of RCS propellant. After that, the operation team changed the software of ground system in order to sweep the uplink frequency at the better spin phase and send commands. By this method, we succeeded to communicate again. Just after the recovery of communication, the received down link power is not enough to demodulate, we utilize the general purpose autonomy functions of DHU (Data Handling Unit) and get the information of the spacecraft. This paper describes these operation methods.

小惑星探査機「はやぶさ」救出運用

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摘要
「はやぶさ」は、2005年12月8日に、RCS起源と思われる外乱により姿勢を喪失し、地球との通信が途絶した。その後、少しでも条件の良いスピン位相の中でアップリンクをスイープしてコマンドを送信するということを実現するよう、地上系ソフトに変更を行い、これにより通信回復を成功させた。また、通信回復直後はテレメトリが復調できないため、DHUの汎用自律化を駆使して、探査機の情報を入手した。これらの運用の内容について述べる。
1. Introduction

The history of Hayabusa rescue operations is shown below.

<December 8, 2005>
The spacecraft was spinning at the spin period of 6 minutes. After the occurrence of disturbance believed to be caused by the leakage of RCS propellant, communication link was lost.

<December 13, 2005>
The rescue operation was started. At the AOS (Acquisition Of Signal), the uplink frequency was swept at the rate of 10Hz/s and range of 18kHz and recovery commands were sent. After that, “100Hz range sweep and partial command sending” sequence was started.

<December 20, 2005>
“42kHz range sweep and whole command sending at AOS” and “100Hz range sweep and partial command sending” sequence was started.

<January 17, 2006>
“42kHz range sweep and whole command sending at AOS” and “200Hz range sweep and partial command sending” sequence was started.

<January 20, 2006>
“42kHz range sweep and whole command sending at AOS” and “7kHz range sweep and whole command sending” sequence for every Friday was started.

<January 24, 2006>
The downlink carrier of Hayabusa was detected. The angle between +Z axis and Earth direction was about 70 degree. Spin period was about 50s and spin direction is around -Z axis.

<January 26, 2006>
1bit communication using general purpose autonomy function of DHU was started.

<February 6, 2006>
Attitude control adjusting spin axis to the sun was started.

<February 25, 2006>
8bps telemetry through LGA (Low Gain Antenna) was established.

<March 1, 2006>
Ranging communication was established.

<March 4, 2006>
32bps telemetry through MGA (Medium Gain Antenna) was established.

2. Operation sequence from December 13, 2005

Uplink frequency was Doppler-aided. After the AOS, whole frequency range was swept and command sequence was sent. Detailed process is shown below.

(1) “Calculated uplink frequency (Doppler-aided nominal frequency) + 2kHz” is set as nominal frequency.
(2) Sweep sequence is started at the rate of 10Hz/s and range of 18 kHz in DEC mode (frequency is changed from low to high). 10Hz/s was selected because received level at the spacecraft must be weak. (Nominal sweep rate is 100Hz/s.)
(3) This process mentioned above covers the range from -16 kHz to +2 kHz of nominal receiver frequency.
(4) After that, commands for DHU set up, antenna change to LGA, XPA-ON, Telemetry modulation off, Coherent mode disable, HCE set up, Spin up by Xe gas, are sent 2 times.

Fig.1 Command Sequence-1 (for AOS)
This process is for the case that the spacecraft can receive commands continuously. Processes for an intermittent case, such as described below, it takes much time to cover whole range. This process and next process are complimentary.

After the process shown above, next process shown below is started.

(1) Offset frequency for the day (-16 kHz for first day. After that, this frequency is depended on that of the day before.) is set.
(2) The sequence show below (4minutes) is executed 3 times (12 minutes).
   ① Sweep 100Hz at 10Hz/s rate incrementally. (10s)
   ② Command modulation on, hold tone (or acquisition sequence; repeated "01" pattern) start, wait 10s. (10s)
   ③ Send DHU set up commands (90s MAX)
   ④ Hold tone stop, command modulation off
   ⑤ Sweep 100Hz at 10Hz/s rate decrementally. (10s)
   ⑥ Command modulation on, hold tone start, wait 10s. (10s)
   ⑦ Send DHU set up commands (90s MAX)
   ⑧ Hold tone stop, command modulation off. (Refer to Fig.2)
(3) The sequence show below (4minutes) is executed 3 times (12 minutes).
   ① Sweep 100Hz at 10Hz/s rate incrementally. (10s)
   ② Command modulation on, hold tone start, wait 10s. (10s)
   ③ Send commands; Antenna changed to LGA-A, XPA-ON, Telemetry Modulation Off, Coherency Disable. (90s MAX)
   ④ Hold tone stop, command modulation off
   ⑤ Sweep 100Hz at 10Hz/s rate decrementally. (10s)
   ⑥ Command modulation on, hold tone start, wait 10s. (10s)
   ⑦ Send commands; Antenna changed to LGA-A, XPA-ON, Telemetry Modulation Off, Coherency Disable. (90s MAX)
   ⑧ Hold tone stop, command modulation off
(4) Increment offset frequency by 100Hz, then, go back to (2). This sequence takes 24minutes/100Hz. (Refer to Fig.3)

3. Operation Sequence Change applied later

<December 20, 2005>
Frequency range of "All range sweep" was changed from -16→+2 kHz to -40→+2 kHz. (Expected receiver frequency is lower than usual when its temperature is lower than operational temperature.)

<January 17, 2006>
Frequency sweep range is changed from 100Hz to 200Hz in order to reduce sequence execution time from 24minutes/100Hz to 27minutes/200Hz.

<January 20, 2006>
"7kHz sweep + Command Sending" sequence was introduced on every Friday. This sequence is effective in the case receive capable time is relatively long. Two kinds of command sequence were sent continuously.

<January 23, 2006>
The downlink carrier of Hayabusa was found. Commands just after "all range sweep" were believed to be executed.

4. 1bit Communication by General Purpose Autonomy
The sequence shown below was executed repeatedly.
(1) Rewrite the general purpose autonomy table.
(2) Enable the autonomy item for check. (Coherency is disabled if this autonomy is executed.)
(3) Disable the autonomy item above after 30s enable.
(4) Go back to (2) in order to check the next item. (5minutes interval)
(5) After all items are checked, go back to (1), and rewrite the next autonomy table.

Notes:
Coherency Enable/Disable is changed by relay action. Therefore, the check method was changed to Telemetry On/Off, which do not use relay.

Execution of "DHU autonomy table rewriting" was assured by conditions shown below.
(1) Continuity of type-A command.
(2) Format error check executed by general purpose autonomy.
(3) Check Sum error check executed by general purpose autonomy.

In order to reduce rewrite data, first autonomy item from the 256bytes boarder of DHU memory allocation were used.

Determined statuses were shown below.
(1) Battery voltage, Battery cell voltages
(2) On/Off statuses of components, Bus current
(3) Health of IES (Ion Engine System); Xe tank pressure, components temperatures.
(4) MGA (Medium Gain Antenna) gimbals temperature.
(5) XSW (X-band Switch) temperature.
(6) Sign of IRU (Inertial Reference Unit) output data. (Spin direction)
(7) TSAS (Two axes Sun Aspect Sensor) Sun Presence.
(8) CSAS (Coarse Sun Aspect Sensor) Sun Presence.
(9) TSAS sun angle latch data; Latch the TSAS data when TSAS sun presence is on and if TSAS sun presence is on in the latch data, stop the latch action. After this event, read the latch data.
(10) RCS (Reaction Control System) tank pressure, temperatures of each part of RCS.

5. Conclusion
"Short time sweep + command send" mechanism to send commands to the target, which cannot receive continuously, is established.
We also established the method to get the information bit by bit, by utilizing a general purpose autonomy function of DHU and checking the received carrier level on the ground. This method can be used in the case no telemetry can be demodulated.