Guidance, Navigation and Control issues for Hayabusa follow-on missions

F. Terui, N. Ogawa, O. Mori
JAXA (Japan Aerospace Exploration Agency)
Lessons and Learned & heritage from Proximity Operation (<50km) of Hayabusa

- measuring relative position and attitude
- controlling relative position and attitude to the asteroid

are not easy tasks for the asteroid that have not seen beforehand

LIDAR
- for altitude measurement
- ONC-W1 (FOV 60degx60deg)
- for Itokawa or Target Marker tracking

LRF
- for attitude and altitude
- FBS (Fan Beam Sensor)
- for unexpected obstacle detection

Rendezvous and landing scenario of HAYABUSA

Navigation sensors of HAYABUSA
Heritage from HAYABUSA and Lessons Learned

1. Successfully performed the approach to Itokawa (approx. 50km → 100m) using ONC-W1 (wide view camera) and LIDAR

   Feature points (“landmark”) in the image of Itokawa were extracted \textbf{manually} on the ground and matched with “3D feature points model” \textbf{manually} on the ground for image based navigation (position)

   \textbf{autonomous on-board visual navigation algorithm} is desirable

   Developing autonomous (not on the ground) \textbf{image based navigation} system exploiting actual images of Itokawa
Technical issues and ongoing research for MP GNC (1/2)

"need to prepare various GNC algorithms for asteroids with various shape, surface, spin rate, etc."

1. Guidance Phase (altitude: approx. 8km → approx. 500m): LIDAR, ONC
whole area of the asteroid e.g. “Itokawa” is in FOV of the Onboard Navigation Camera

autonomous measurement algorithms are now under development
1. centroid extraction algorithm → already developed
2. silhouette based 3D model matching algorithm for relative position measurement
3. autonomous GCP(Ground Control Point)-NAV algorithms onboard
   ➢ feature points extraction algorithm
   ➢ autonomous navigation and guidance algorithm using GCP data base
Autonomous Matching
Using Asteroid’s Silhouette (1/2)

Guidance Phase (8km-500m approx.):
Too far for GCP-NAV
The whole asteroid is inside the FOV ➔ Use Silhouette of the Asteroid

![Real Images](image1)

![Silhouette](image2)

On-Board Autonomous Matching with 3D Model
➔ Relative Position
Simulation results using Itokawa images indicated **the performance comparable to the actual ground operation** (matching by human) → The validity was confirmed
GCP such as feature points extraction algorithm developed using images of “Itokawa”

1. construct **template of feature points** using images taken at the **1st TD** (2005/11/19)
   (e.g. feature point “$4$” in the 1st TD image is used as the sample feature point)
2. autonomous **matching** of templates with images taken at **2nd TD** (2005/11/25)
   (e.g. corresponding place in the 2nd TD image is extracted applying correlation based matching)
Autonomous GCP-NAV algorithms onboard (2/5)

Guidance and Control strategy
exploiting GCP(feature points) on JU3

**algorithm**

1. **construct “GCP 3D data base”** using images taken during the rehearsal approach (altitude: 600[m] → 100[m])
2. **extract GCP** in the image taken during the actual approach phase
3. **calculate position difference** between
   - virtually-imaged estimated position of GCP from “GCP 3D data base”
   - extracted GCP position in the actual image
4. the above difference is used as a input to **Kalman Filter** and relative position/velocity are estimated and used for **position guidance**

**assumption**

- attitude motion of JU3 is **one-axis spin** and its attitude is given as a **function of time**
- attitude of the probe is measured correctly
Numerical Simulation of GNC for the approach to JU3

- Navigation using image from **one onboard camera** with FOV 60 [deg] x 60 [deg]
- Navigation using **GCP 3D data base** and recognized GCP position in the image
- **Approach phase**: going down toward the center of the asteroid
- JU3 is assumed to be one-axis (Z) spinning with its period of 7h32m38s
Autonomous GCP-NAV algorithms onboard (4/5)

GCP 3D data base for JU3

- Appropriate distribution of GCP with various size
- Particular area for closer view at the rehearsal approach has much more GCP with smaller size
- The rehearsal approach and the actual approach have similar trajectories in order to get similar views
Autonomous GCP-NAV algorithms onboard (5/5-a)

Result of the numerical simulation of GNC for the approach to JU3

→ successfully approached to the JU3

Rehearsal approach

Actual approach
Autonomous GCP-NAV algorithms onboard (5/5-b)

Result of the numerical simulation of GNC for the approach to JU3

- Lateral direction position control with interval of 1200[sec] was started after 1800[sec] waiting for the convergence of the image based navigation error.
- Vertical direction position control with interval of 1200[sec] was started after 1800 [sec] waiting for the convergence of the image based navigation error.
- Vertical direction velocity control with interval of 60[sec] was started from the start of the manoeuvre.

Æ Successfully approached to the JU3.
Technical issues and ongoing research for MP GNC (2/2)

2. Vertical Descent Phase (altitude: approx. 500m → approx. 40 m)
   - LIDAR, ONC (Onboard Navigation Camera)
     - a part of the asteroid e.g. “Itokawa” is in FOV of the vision sensor

- autonomous measurement algorithms are now under development
  - GCP-NAV algorithms onboard
    - robust feature points extraction algorithm
    - autonomous matching algorithm between feature points
  - autonomous 3D model matching algorithm utilizing image features
Terrestrial experiment asteroid model for development/evaluation of algorithms

development and evaluation of algorithms using
- Computer Graphics
- images given from terrestrial experiment with parallel light facility

asteroid model & scan-type Laser Range Finder for measuring 3D shape of the model

measured 3D shape of the asteroid model