MICROGRAVITY ROBOTICS FOR SAMPLING AND IN-SITU SCIENCE MISSIONS. Kazuya Yoshida, Tohoku University, Graduate School of Engineering, Dept. of Aerospace Engineering, Aoba 6-6-01, Sendai 980-8579, Japan, yoshida@astro.mech.tohoku.ac.jp

Introduction: Detailed exterior appearance, surface material compositions and key evidences to infer the interior of some of the asteroids and comets have been revealed by recent space robotic probes. Particularly in 2005, a couple of challenging attempts have been successfully conducted and then enlarged our view of minor bodies. One is Deep Impact mission to collide and create a crater on comet 9P/Tempel 1. The ejecta from the crater were observed from the spacecraft itself and a number of telescopes on Earth and in space, then their volatile compositions were quantified [1]. The other is Hayabusa mission to asteroid (25143) Itokawa. The target is a tiny S-type asteroid but after the close encounter observation, Itokawa turned out to be a rubble pile of loose-packed rocks that we have never seen closely before. Hayabusa also conducted a touch-and-go type of proximity operation. The purpose of the operation is to collect material samples from the surface and bring them back to Earth. To know the result of this challenging sample-return attempt, we have to wait until the spacecraft’s safe return though, the robotics based navigation and sampling technology has been proven [2].

As technology candidates for follow-on minor body missions, there are a variety of designs studied in robotics community. One aspect of the study is the improvement of the impact sampling probe to conserve the geological stratigraphy of the target from outer surface to interior. Another aspect is a stable mobility on microgravity surface for in-situ observation and analysis on different locations specified by scientists.

In this paper, the author will make a quick review on the design consideration of the touch-and-go type of impact sampling selected for Hayabusa and the process of design evaluation. Then the focus will be extended to a possibility of surface locomotion by a robotic devise.

Sampling Strategies: Key consideration in the sampling on a minor body is versatility to microgravity environment and unknown hardness of the surface. As a general discussion, the strategies depicted in Figure 1 have been discussed as possible candidates for the Hayabusa mission [3]. (a) Drilling is a common idea to obtain core samples from surface to interior. However to achieve the drilling, the spacecraft must be anchored firmly on the surface to accommodate the reaction. Both drilling and anchoring will be possible on soft surface, such as the surface of a comet, but difficult on an asteroid. (b) Penetrating a sampling probe into the target from some distance can be a promising idea. If properly designed, samples will be packed in the penetrator keeping the geological stratigraphy, and if tethered they can be retrieved. In this strategy, the spacecraft needs hovering over the sampling site, then deploy and retrieve a tethered object, which will involve design complexity. (c) If a bullet or cannon-like projectile is projected with certain velocity, the surface will be crashed and fragments are ejected. An idea is to combine Deep Impact-like impact crash and Stardust-like dust collection technologies. But since the sample collection will be conducted at some distance from the impact site, the registration of the original sample location is difficult. (d) Another idea is to collect the crushed fragments on or at close vicinity of the surface. In this option, the spacecraft is required to make physical contact with the surface although, samples are efficiently collected from a specific point of interest on the surface. For the Hayabusa spacecraft we selected this strategy, and a number of tests were conducted to refine this design in terms of amount of sample collection and spacecraft safety in the touch-and-go maneuver [3].

Figure 1: Sampling strategies on a minor body

Figure 2: Design configuration of Hayabusa probe
Surface Mobility: As a challenging option, Hayabusa carried a tiny robotic system named Minerva that weighs less than 1 kg, yet capable to locomote on the surface of the target asteroid. The principle idea of the Minerva locomotion is to use an internal reaction wheel to tumble the robot body itself, then hit and hop over the microgravity surface. It has a drawback that the destination of each hopping maneuver is difficult to control, but this unique robotic devise must have provided amazing close-up pictures of the Itokawa surface. However, unfortunately, Minerva did not arrive on the Itokawa surface because of difficulty in the descending maneuver of Hayabusa on Nov. 12, 2005.

Another idea for surface mobility is to employ articulated mechanism like limbs of a human body or an insect or a spider. Those living creatures can hold on a rough surface and climb a rocky wall. This becomes much easier in microgravity environment [4]. Figure 3 describes a conceptual design and its hardware test bed. In the presented design, the rock-climber robot has six articulated limbs. In principle, three limbs are used to hold the surface while another three can move toward arbitrary direction. Such a robotic system could offer more of proximity surface science opportunities in near future though, since the robot has 18 active joints, the complexity in design and control is a drawback that we have to solve as an engineering issue.