Motion Estimation of Autonomous Spacecraft near Asteroid Using Wide-Field-Integration of Optic Flow

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Autonomy is a key technology for space exploration missions; it expands the frontier of human activities considerably. Although remote commands for exploration probes from Earth are effective for near space missions like activities on Moon, deep space exploration missions need autonomous technologies due to extremely long delay time of signals: for instance, the signal delay between Mars and Earth becomes 4-20 minutes according to the relative positions of the two planets. Thus, since quick response is required for near asteroid surface motion, an autonomous system is indispensable. In addition to the autonomy, for deep space probes, the restrictions of size and weight become stricter. Furthermore, we should take into consideration that computer performance for space systems is relatively low, that Global Positioning System (GPS) cannot be utilized, and that a priori environmental information of a target asteroid is not sufficient for autonomous motion.

In this study, visual-based navigation system inspired by biological research is applied to a deep space probe to cope with the problems addressed above. Wide-Field-Integration (WFI) of optic flow ([1], [2]) is a relative motion estimation technique mimicking visual processing in compound eyes of some flying insects; e.g., bees, flies, and dragonflies. Optic flow is the vector field of relative velocities obtained by photoreceptors. It is produced by motion of a projected image over the surface of retina, and WFI of optic flow utilizes a wide range of optic flow for estimation of motion. This integration process generates several preferable features for deep space exploration systems. First, the estimated results are robust for the surface of asteroids, thus it is effective even for uncertain environments. Second, a small size, light weight, and low resolution image sensor is acceptable, because accuracy of optic flow is less important in the integration process. And finally, the computational load becomes small and quick response is possible, because it does not require many flow data in the estimation process.

However, the WFI of optic flow is hardly considered in guidance and navigation of space probes, especially there is no research for practical hardware systems. The main reason comes from the theoretical assumptions in the estimation process. The theory of WFI of optic flow assumes that optic flow is obtained in the whole area of a spherical image surface around the vehicle's mass center; however in a real system, optic flow is obtained from an image sensor with a limited field of view. Thus, even with multiple cameras, this assumption is not realistic. Furthermore, the image surface of a standard camera is flat, and sensor outputs include noises.

In this paper, the effects on estimation accuracy for three parameters of image sensors (a number of cameras, field of views, and the directions of optical axes) are discussed considering sensor noises. The effects for these parameters are also examined in two cases, with and without gyro sensors; in the former case only translational motion variables are estimated, but the latter estimates both translational and rotational motion variables simultaneously. These numerical discussions suggest that how we should design image sensors according to mission scenarios, e.g., landing or surveillance mission. Furthermore, the estimation accuracy of the WFI of optic flow is also evaluated in experiments using MAV. Figure 1 shows a typical result: red lines are estimation result from WFI of optic flow for six motion parameters, and black lines are motion variables measured by other sensor.

1] Franz, M. O., and Mallot, H. A. “Biomimetic Robot Navigation” Robotics and Autonomous Systems, Vol. 30, Nos. 1-2, pp. 133-153, 2000.

[2] Humbert, J. S., and Hyslop, A. M. “Bio-Inspired Visuomotor Convergence” IEEE Transactions on Robotics, Vol. 26, No. 1, pp. 121-130, 2010.

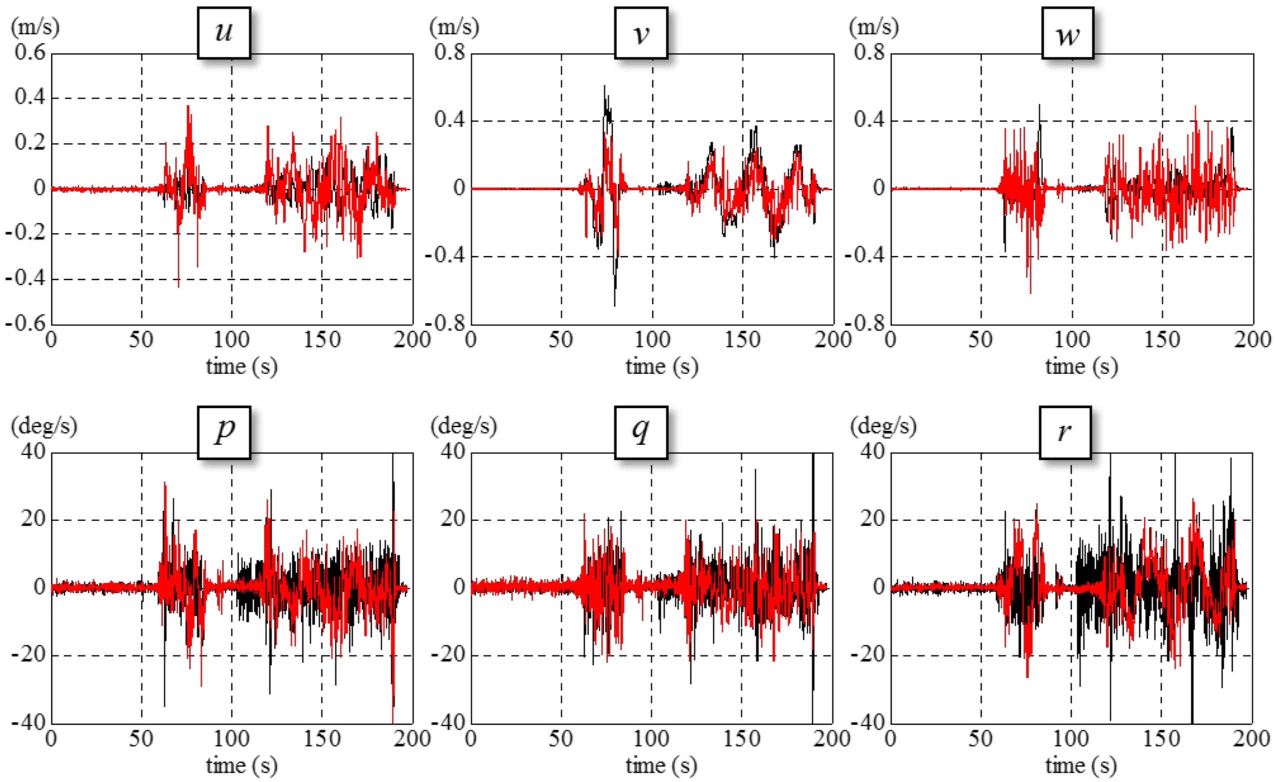

Figure 1. A typical estimation result in experimental evaluation