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AUTONOMOUS OPTICAL NAVIGATION USING FPGA-BASED VECTOR CODE CORRELATION ALGORITHM FOR DEEP SPACE MISSIONS

Abstract

This paper describes an autonomous optical navigation to estimate the relative position of a spacecraft with a target body and control it for explorations to small solar system bodies. In the case of Hayabusa2, the asteroid sample return mission of JAXA, the asteroid-relative position is estimated by ground operators. On the other hand, in the case of explorations to small bodies farther than Main-belt, the communication delay is unacceptably large for the asteroid-relative feedback guidance. This situation becomes worse for larger asteroids because the time constant of the dynamics becomes faster. Therefore, importance of on-board optical navigation is highlighted for explorations to far distant small bodies. To accomplish on-board optical navigation, the Vector Code Correlation (VCC) algorithm suitable for FPGA is focused on. This method is a type of template matching that finds the most similar part of 2 images by comparing them. In the case of the VCC algorithm, by discretizing slope of luminance in images into 3 patterns, data size of each pixel can be reduced from 8 to 4 bit without losing feature such as edges. Therefore, their correlation can be calculated at high speed via XOR operations on FPGA. The advantage of this method is that it can be applied to bodies with relatively flat surface because it uses slope of luminance for matching. In this study, the VCC-based position estimation method was developed and implemented on an FPGA board. The estimation accuracy and computation time are evaluated by comparing the proposed method with other position estimation methods. The proposed method mainly consists of 2 steps: rendering to generate a reference image from the nominal position and the 3D shape model of the target body; estimation of the pixel shift between a captured image and a reference image by the VCC algorithm. In addition, the VCC algorithm on multiple planes in images was implemented in order to improve the estimation accuracy at low altitudes, where the outlines of the asteroid cannot be seen in the images. As a result, the position estimation accuracy of approximately 1 pixel size in real space is achieved. Furthermore, the proportional-integral control system using the proposed method was designed for guidance control. Finally, by demonstration of the system to the flight data of Hayabusa2 in landing phase, it was found that it can be applied to a real mission environment from the aspect of estimation accuracy and computation time.