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REAL-TIME OPTICAL NAVIGATION BY PERSPECTIVE PROJECTION ESTIMATION USING SHAPE MODEL FOR FAR-DISTANT SMALL BODY EXPLORATIONS

Abstract

This paper describes autonomous optical navigation to estimate relative positions of a spacecraft with a target body for far-distant small body explorations. The small body explorations have received attention around the world in recent years. In these missions, high-accuracy optical navigation is important for the landing or rendezvous. Therefore, Terrain Relative Navigation (TRN) to estimate deviations by comparing nominal terrain information with actual terrain information is often used. Enough observation of a target body to make a shape model is possible after arrival, especially in the small body explorations. Accordingly, the shape model of the target body is utilized for the generation of the nominal terrain information. In the case of near-Earth asteroid exploration spacecraft Hayabusa2, ground-based navigation using communication with the Earth is used. On the other hand, in the case of explorations to small bodies farther than the asteroid main belt, communication delay with the Earth is unacceptably large for feedback guidance. This situation becomes worse for larger bodies because the time constant of the dynamics becomes faster. Therefore, the importance of high-accuracy real-time autonomous navigation is highlighted for explorations to the far-distant small bodies. In this study, an autonomous optical navigation method based on TRN is proposed. Firstly, the reference image from a nominal position is generated by rendering in the case of the proposed method. Three-dimensional positions on the shape model relative to each pixel of the reference image are also memorized in addition to luminance. Secondly, multiple small images extracted from the reference image are compared with a captured image by template matching. Therefore, the relationships between the three-dimensional positions on the shape model and the multiple small images in the captured image can be determined. Finally, the actual position of the spacecraft can be determined by estimation of perspective projection, that projects a three-dimensional shape onto a two-dimensional plane. In this study, Vector Code Correlation algorithm for correlation calculation of template matching is used. Therefore, the correlation of images can be calculated via XOR operations suitable for FPGA. For these reasons, three-dimensional positions of the spacecraft can be estimated in real-time by utilizing the shape model. The estimation accuracy and computational time are evaluated by comparing the proposed method with other methods. As a result, the high estimation accuracy of several image resolution in real-time is achieved. The authors believe that the proposed method will be a key technology for far-distant small body explorations.