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LANDMARK-FREE OPTICAL NAVIGATION AROUND SMALL BODIES: APPLICATION TO THE HAYABUSA2 TOUCHDOWN ON RYUGU

Abstract

Recently, many missions that explore small bodies such as asteroids or comets are producing remarkable results. In particular, the missions that perform landing on the target bodies are gathering attention. The Japanese asteroid explorer Hayabusa2 accomplished the first touchdown on the asteroid Ryugu on February 21, 2019. This kind of operation requires highly precise navigation relative to the target bodies. Hayabusa2 uses a method that compares the landmarks detected in the surface images to the landmark database created beforehand. Although various studies about landmark-based navigation have been reported, they depend on the terrain surface. In the case of landing, the landing site may not contain sufficient landmarks because smooth areas tend to be selected for safety reasons. A method called simultaneous localization and mapping (SLAM) is known to be powerful when the spacecraft position and asteroid shape are to be estimated simultaneously. However, the mapping process is redundant in the case of critical operations such as landing because precise shape models are available before such operations, as shown in the example of Hayabusa2. Moreover, this method has a problem called loop closure: the map must be closed to remove the influence of error accumulation. This study proposes a navigation method that does not use landmarks but uses terrain information. The small areas, rather than points, are tracked in the sequential images, enabling the visual tracking without relying on local features. Small search windows cut out from an image are tracked in the next image. A method called phase-only correlation is used to make the tracking be robust to the change in scale and rotation. The search windows are given by projecting the vertices selected from the shape model on the camera screen, removing the landmark detection process. The spacecraft position is estimated by solving the nonlinear equations of projection transformation for the tracking results. Here, the positions of the search windows in the real space must also be solved to correct projection errors. The positions of the selected vertices are given as the initial guess for them, which enhances the convergency of the solution. In addition, the loop closure problem does not occur because the solution is based on the vertices that are already known precisely. The developed method is validated using the result of the Hayabusa2 touchdown operation. The estimation result of the developed method is compared to that of the nominal navigation method used in the Hayabusa2 mission.