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# VISION BASED NAVIGATION FOR AUTONOMOUS PINPOINT LUNAR LANDING

**Abstract**

Space missions that involve landing on planets, moon, comets and asteroids are inherently challenging. Autonomous landing spacecraft to the pre-selected landing zone with high scientific value, especially in an area of rough terrain, require high precision navigation method. In order to achieve pinpoint lunar landing, NASA, ESA and JAXA are pursuing vision-based navigation technologies to realize landing error within 100 meters. There are two main vision based navigation function: landmarks based global position estimation and feature flow based velocity estimation. However, both the two navigation methods have its shortage, crater landmarks cannot be extracted or matched during the last stage of the descent due to the database's finite resolution of landmarks, while the feature flow based relative velocity estimate method result in large landing error due to error accumulation. In this work, we present a vision based navigation algorithm which integrate the feature flow and crater landmarks to capture both of their advantages and achieve a better navigation result. Firstly, the basic principles of spacecraft's motion parameters estimation with crater landmarks and opportunistic features are given. Crater landmarks whose 3D positions can be pre-determined are the most notable lunar terrain features, it clearly distinguishable all the way from approach to the moon to a very low lunar orbit. Arbitrary choose 4 matched crater landmarks, the spacecraft's motion parameters can be estimated from the geometry of associated line-of-sight vectors directly. Opportunistic features can be detected by the famous Kanade-Lucas-Tomasi (KLT) method, the KLT feature detector operates by comparing a patch of image information of two consecutive frames of an image sequence to achieve feature tracking. The tracked features 3D position in camera coordinate system contains the relative position and attitude of spacecraft. Secondly, extend Kalman filter (EKF) is researched to integrate the crater landmarks and opportunistic features to estimate the 6Dof motion parameters of spacecraft. Choose spacecraft's 6Dof motion parameters (position and attitude) and the opportunistic features' global positions are the filter state variables. The EKF measurement are the image coordinates of crater and opportunistic features, in addition the altitude of spacecraft to lunar surface is provided by an altimeter. The integration of the measurement of crater landmarks and opportunistic features provides a more precise and robust navigation solution. Lastly, simulation result will be given to show the accuracy improvement of this approach to either the feature flow or the crater landmarks based navigation and some analysis will be given.