Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 53 (2014) 1810–1821

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

A new approach based on crater detection and matching for visual navigation in planetary landing

Meng Yu *, Hutao Cui, Yang Tian

Department of Deep Space Research Center, Harbin Institute of Technology, No. 2 Yi Kuang Street, Hei Longjiang 150000, China

Available online 23 April 2013

Abstract

This paper provides an approach of crater detection and matching to visual navigation in planetary landing missions. The approach aims to detect craters on the planetary surface and match them to a landmark database during the descent phase of a planetary landing mission. Firstly an image region pairing method is proposed to detect the crater by using an image region feature detector. Then a WTA-rule is adopted to match the detected crater to the crater in database. To further reduce the false matching rate, an efficient method for reducing false matches using parameters of crater in 3-D database is proposed. Real images of planetary terrain and a semi-physical planetary landing simulation platform are utilized to test the performance of the approach, simulation results show the proposed approach is able to match the required number of craters to the database for pin-point planetary landing with a low rate of false detection and false matching, which will lead to an improved planetary landing precision.

Keywords: Crater detection; Crater matching; Feature detector; Visual navigation; Planetary landing

1. Introduction

Landing on an extraterrestrial planet is a complicated yet exciting aspect of many planetary exploration missions, where the autonomous guidance and navigation technique is highly required due to the communication delay between lander and earth. Some future planetary missions may undertake the responsibility for in-situ scientific investigation which may require a pre-defined landing spot and pin-point landing technique (Epp et al., 2007), however, current Entry, Descent and Landing (EDL) navigation methods are far from this capability. Hence a navigation system that meets the needs of precise pin-point landing (PPL) mission is required for the future planetary lander (Bach Van Pham et al., 2010).

The terrain-based vision navigation technique allows the lander to determine its own position with respect to a known reference and navigate to the landing spot by recognizing several landmarks on the planetary surface, which caters to the requirements of PPL. (Cheng and Ansar, 2005). Such navigation system relies on one or several passive/active optical sensors (such as camera, Lidar), and the inputs of such system are a reliable number of visible landmarks, among which crater is considered as an ideal guidepost due to its illumination and scale invariance properties and cratered characteristic of planet (Cheng and Miller, 2003).

To achieve the goal of crater recognition based visual navigation, crater needs to be extracted from the image acquired by on-board camera during the descent phase and matched to the same crater with known position in database. Many scholars have focused on the research of crater detection and matching since the successful landing mission of Near Earth Asteroid Rendezvous, (Agrawal et al., 1993) where the lander used the centroid of crater as persistent feature to navigate while approaching asteroid Eros433. Some traditional methods, such as voting technique and Hough transform were introduced in the field of crater detection (Honda et al., 2000; Costantini et al.,

* Corresponding author. Tel./fax: +86 451 86402608.
E-mail address: yumeng@hit.edu.cn (M. Yu).

0273-1177/$36.00
http://dx.doi.org/10.1016/j.asr.2013.04.011

2003; Flores-Méndez et al., 2003; Kim et al., 2005). In order to make the detected crater as a good navigation-aid feature, other common methods have been implemented in crater detection algorithm, such as edge detection, gradient filtering, neural network, etc. A review of using several image processing techniques to detect craters with detailed description can be found in (Troglio et al., 2009). One method worthy of mention is the method developed by NASA's visual navigation group (Cheng et al., 2005), first an edge detector named Canny operator is introduced to extract the edge information in a given image, then an edge grouping approach is used to group detected edges belonging to the same crater, a closed ellipse is fitted to represent the crater and matched to the same crater in database. The proposed method is tested on the image sequence acquired from NEAR's landing mission, simulation results indicate that the method can satisfy the requirement of PPL mission aiming at landing on small cratered asteroid (100 m of landing precision), which makes Cheng's method (for brevity) a milestone in the development of crater detection and matching algorithm (CDMA).

In addition, some scholars have also developed CDMAs with the usage of innovative methods. Yang et al. (2011) used biologically inspired based Haar-feature (BIF) to detect craters on Mars, by combining the advantages of biological model and Haar-features, the algorithm can achieve discriminative information from detected crater and give its detailed description. Wokes et al. (2010) developed a novel crater recognition based method for navigation in lunar landing mission, in which the detected craters are approximated as discs and reconstructed as spherical models, from with the pose information of detected crater is derived and used as invariant to crater matching, the proposed method has been tested on the images containing simulated craters with acceptable crater matching/false matching rate for navigation.

As the spacecraft is required to land on a pre-defined spot with high precision in PPL mission, the on-board navigation system should be capable of estimating the pose of spacecraft with respect to the landing spot. Since a landing spot is often selected from flat areas for safety issues, its image intensity variation is highly limited, which makes it very difficult to detect and match to database (with known position). Since crater is a persistent landmark on planetary surface, its absolute position with respect to landing spot can be obtained off-line, thus the lander's pose with respect to the landing spot can be indirectly obtained by determining the lander's pose with respect to crater with known absolute position, therefore crater detection and matching algorithm (CDMA) can be efficiently used in navigation for PPL.

However, many existing CDMAs lack robustness when dealing with detecting aged craters, especially in the situation of complex image texture background. Also, some CDMA requires a good initial estimation of lander's pose, which might not be expected in some extreme landing situations. In order to overcome the disadvantages mentioned above, a new approach of crater detection and matching algorithm mainly based on image region feature is proposed in this paper. The structure of this paper is organized as follow: the second section introduces the crater detection algorithm, the third section focuses on the problem of crater representation by combining image region information and Canny operator, also the progress of crater matching is stated. The fourth section proposes a

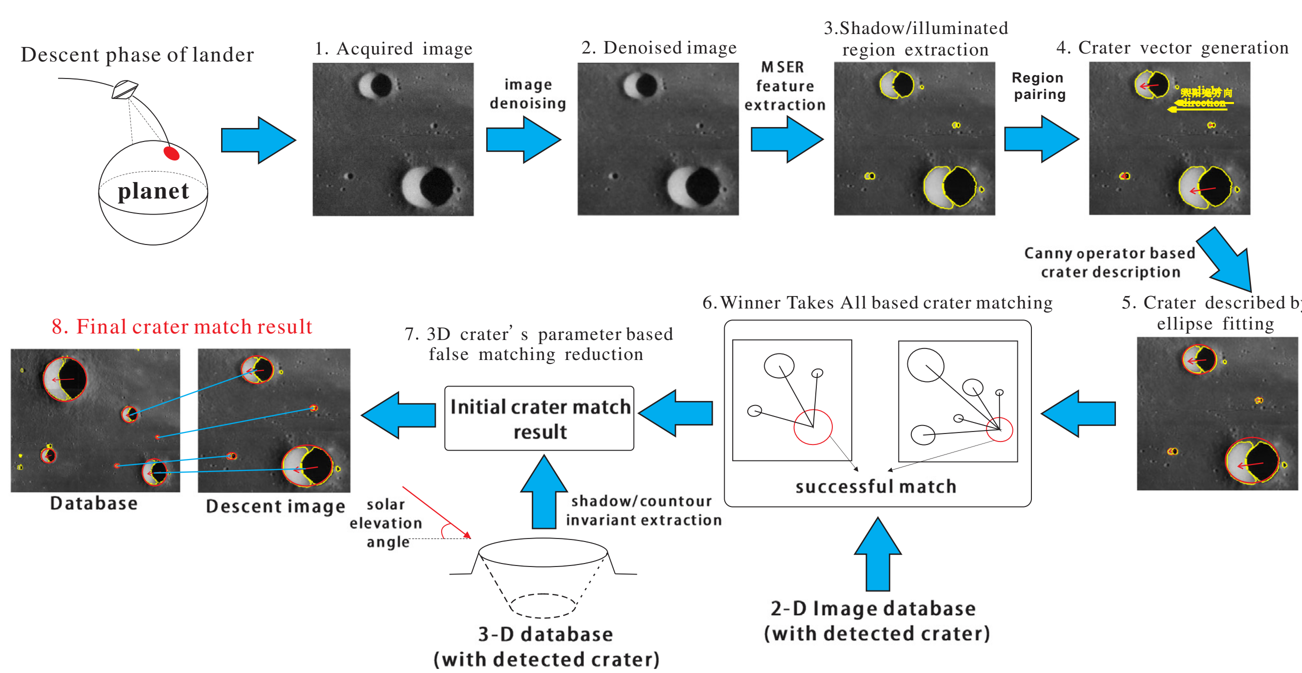

Fig. 1. Conceptual overview of crater detection and matching approach proposed in this paper.