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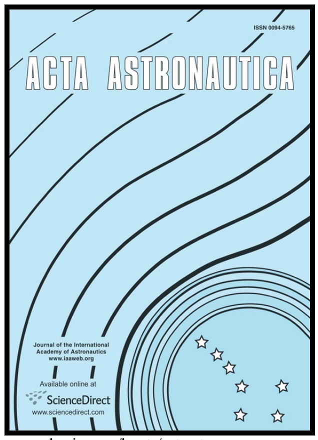

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Innovative Hazard Detection and Avoidance Strategy for Autonomous Safe Planetary Landing

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Abstract

Autonomous hazard detection and avoidance (AHDA) is one of the key technologies for future safe planetary landing missions. In this paper, we address the latest progress on planetary autonomous hazard detection and avoidance technologies. First, the innovative autonomous relay hazard detection and avoidance strategy adopted in Chang'e-3 lunar soft landing mission and its flight results are reported in detail. Second, two new conceptual candidate schemes of hazard detection and avoidance are presented based on the Chang'e-3 AHDA system and the latest developing technologies for the future planetary missions, and some preliminary testing results are also given. Finally, the related supporting technologies for the two candidate schemes above are analyzed.

1. Introduction

In order to obtain more scientific return, a growing number of planetary pin-point landing missions are taken into account, which involves safely landing a spacecraft on the hazardous terrain with high scientific value. Autonomous hazard detection and avoidance (AHDA) is one of the essential technologies for future robotic or manned Moon sample return and Mars landing missions [1,2]. With the development of onboard hardware and software technologies and challenging needs for new missions, the AHDA strategy should be further developed.

It is well-known that Apollo lunar excursion module is the first lander to perform soft landing with hazard avoidance, but it is achieved by the crew not performed automatically [1-3]. In recent years, AHDA technology for safe planetary pin-point landing has been paid much attention by NASA, ESA, and Chinese aerospace agencies. NASA's Autonomous precision Landing and Hazard detection and Avoidance Technology (ALHAT) program is to develop precise landing and hazard avoidance system technologies for manned and robotic planetary pin-point landing missions [1,4-6]. ESA has also developed the new-generation landing systems with the capability of precise landing and autonomous hazard avoidance in order to explore the high scientific value but hazardous areas [7,8].

Due to the long communication delay induced by the large distances between the target planets and base stations on the Earth, together with the limited capability of traditional planetary landing Guidance Navigation and Control (GNC) mode, all planetary landers to date, except for Chinese Chang'e-3 lunar lander, have no AHDA capability during landing period [2]. In December 2013, Chinese Chang'e-3 adopted relay autonomous hazard avoidance strategy, in which the autonomous hazard avoidance operations are divided into two successive sub-phases. The coarse avoidance is firstly implemented, and then the precise avoidance is done [2]. During the Chang'e-3 landing, there is no manual intervention from the altitude of ~15km (de-orbit) to touching down on the lunar surface. The main capabilities and achievements of AHDA system demonstrated by Chang'e-3 include [2,9-12]: (1) completely autonomous guidance, navigation and control without any manual intervention; (2) two-dimensional (2D) gray imaging (using optical grey camera) on the height of ~2km above lunar surface, and