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An Environmental Estimation Model for In-situ Measurements of Small Space Debris

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Abstract

Space debris smaller than 2 mm that cannot be detected by ground-based observations may lead to a spacecraft's missions end. Therefore, IDEA, the project for In-situ Debris Environmental Awareness, which aims to detect sub-millimeter-size debris using a group of micro satellites, has been initiated at Kyushu University. To estimate the debris environment based on in-situ measurements from the project, this paper proposes an environmental estimation model with a Sequential Monte Carlo (SMC) filter. First, this paper reviews the previous research that investigated the nature of an orbit on which a piece of debris can be detected through in-situ measurements, and applies this phenomenon to the algorithm of the SMC filter. Second, the proposed model is evaluated by a simulation using MASTER-2009, which is the environmental model developed at European Space Agency. Comparison between the debris distributions predicted by MASTER-2009 and the simulated estimation verifies that the proposed model can estimate the debris environment sufficiently. Finally, this paper also investigates the effect of the measurement duration on the estimation. It is concluded, therefore, that the estimation model proposed and evaluated in this paper can provide a better definition of the sub-millimeter-size debris environment with in-situ measurements.

Keywords: Space debris, Environmental modeling, Small satellite, In-situ measurement, Sequential Monte Carlo

1. Introduction

The number of non-functional artificial objects orbiting the Earth has increased through humankind's outer space development and activity. Those objects called space debris are one of the major risks to spacecraft because an impact of a piece of space debris on a spacecraft can cause a breakup or fatal damage. Space debris larger than approximately 10 cm, which can cause a catastrophic collision with a spacecraft, can be detected and tracked by ground-based observations, so that operational spacecraft can conduct collision-avoidance maneuvers (Mehrholz et al., 2002). Mehrholz et al. (2002) also reported that debris between 2 mm and 10 cm in size are observable (e.g. Haystack radars), thus a collision with those debris can be predicted statistically. However, space debris smaller than 2 mm cannot be detected nor tracked by ground-based observations. Therefore, a spacecraft cannot avoid nor predict a collision with a sub-millimeter-size debris. Nitta et al. (2010) reported that a simulated debris particle with a size of approximately 0.3 mm fractured the power cables of a spacecraft. This kind of damage might be the cause for loss of power, which is believed to have happened to the Japanese ADEOS 2 spacecraft in October 2003 (Neish et al., 2005). In fact, impacts on spacecraft with sub-millimeter-size debris have been observed in the actual space environment. For example, the US Space Shuttle Endeavour and Atlantis have received a number of small impact features caused by sub-millimeter-size meteoroid or debris impacts on their radiator panels (Hyde et al., 2007; Lear et al., 2008). Another example is impact damage on solar arrays of the International Space Station reported by Christiansen et al. (2014). Therefore, knowledge of sub-millimeter-

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