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SINGLE-SATELLITE REAL-TIME POSITIONING OF BALLOON AND HELICOPTER FOR AERIAL EXPLORATION IN EXTRATERRESTRIAL ATMOSPHERE

Abstract

This paper describes a positioning method and its associated mission concept that enable the use of one orbiter in a well-designed frozen elliptical orbit to perform real-time three-dimensional (3D) positioning of a balloon or a helicopter buoyant in the atmosphere of Mars, Venus, or Titan. The orbiter performs 2-way proximity link communications with the balloon or helicopter, and simultaneously measures the range and Doppler – Joint Doppler and Ranging (JDR). For the rest of this paper, we describe the method and its performance in the context of tracking a balloon in the Venus atmosphere.

We assume that the balloon is deployed near the equator of Venus. To maximize the visibility between the orbiter and the balloon, we consider using a frozen elliptical orbit whose apogee does not drift for a long period of time. Due to the slow rotation rate of Venus, we explore the design space of the orbit using the J2, J3, and J4 terms of the Venus gravitational model. The candidate frozen orbits are then evaluated based on their coverage, range, and velocity with respect to the balloon. A 6-hour orbit that is 53 degree inclined with a semi-major axis of 15687 km is chosen to illustrate the performance of the positioning scheme. The range between the South Pole and the apogee is about 19 thousand kilometers. A 24-hour frozen orbit is also considered. In this case, the orbit offers longer continuous tracking time, but higher South Pole – apogee range of 57 thousand kilometers.

With reasonable range and Doppler measurement assumptions, we show by simulations that the real-time 3D positioning Root-Mean-Square-Error (RMSE) performance is less than 20 meters for the radar altimeter case (with 1-sigma error of 10 meters), and is less than 90 meters for the barometric altimeter case (with 1-sigma error of 75 meters). It is expected that this kind of positioning accuracy would enable new exploration concepts and science measurement campaigns in extraterrestrial atmospheres.

We also discuss the availability of existing near-Earth and deep space proximity link radio systems that either possess all the capabilities, or only require minor modifications to perform the JDR operation for 3D positioning.