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SINGLE-SATELLITE REAL-TIME RELATIVE POSITIONING FOR MOON AND MARS

Abstract

In addition to communication coverage, robotic and human explorations of Moon and Mars require location awareness to supporting various activities on the surface and on orbit. This paper introduces a single-satellite localization scheme that leverages on the communication signals to perform Doppler measurement in addition to range measurement to execute a real-time position fix. We call this scheme Joint Doppler and Ranging (JDR) scheme. In this paper we consider the case of relative positioning when there is a nearby reference station. For example, vehicles operating in the vicinity of the landing sites on Moon and Mars.

We assume the satellite can perform "one-to-one" ranging with one receiver at a time. Both a reference station and the user can perform their Doppler shift measurements along their respective radial directions to the satellite. No time information is needed in the Doppler and ranging operations, and there is no time bias. Thus, a minimum of three mathematical expressions are needed based on known user's altitude and Doppler and range measurements between the satellite, and the user and the reference station at a given time-point to perform a real-time position fix:

1. A Doppler equation that includes two Doppler measurements: one between the satellite and the user, and the other between the satellite and the reference station. 2. A range equation for one range measurement between the satellite and the user. 3. A surface constraint equation assuming that the user's altitude on the surface of the planetary body is known.

The JDR scheme is particularly useful to provide real-time 3-dimension (3D) positioning services with a small number of navigation nodes (as small as one) for a user on the Moon and Mars that uses only proximity link radios with ranging and Doppler measurement capability. No separate dedicated navigation radio is required. With more satellites, the surface constraint assumption can be disregarded, and/or the real-time 3D positioning accuracy can be improved.

In this paper, we describe the positioning scheme and its performance in the context of navigation tracking of a user on the Lunar South Pole surface with a reference station in its vicinity, and a Lunar Relay Satellite (LRS) in an elliptical frozen orbit with high visibility over the South Pole. With reasonable assumptions on measurement errors, we show by simulations that the Root-Mean-Square-Error (RMSE) performance of the relative positioning are 10.0 meter in the pessimistic case, and 7.8 meter in the optimistic case.