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Smoothing for ZUPT-aided INS

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ABSTRACT

Due to the recursive nature of most foot-mounted zero-velocity-update-aided (ZUPT-aided) inertial navigation systems (INSs), the error covariance increases throughout each step and "collapses" at the end of the step. This gives sharp corrections and discontinuities in the estimated trajectory. For applications with tight real-time constraints, this behavior is unavoidable, since every estimate corresponds to the best estimate given all the information up until that time instant. However, for many applications, some degree of lag (non-causality) can be tolerated and the information provided by the ZUPTs at the end of a step, giving the sharp correction, can be made available throughout the step. Consequently, to eliminate the sharp corrections and the unsymmetrical covariance over the steps, the implementation of a smoothing filter for a ZUPT-aided INS is considered. To our knowledge, no formal treatment of smoothing for such systems has previously been presented, even though an extensive literature on the general subject exists.

Owing to the customary closed-loop complementary filtering used for aided INS, standard smoothing techniques cannot directly be applied. Also since the measurements (the ZUPTs) are irregularly spaced and appears in clusters, some varying-lag smoothing rule is necessary. Therefore, a method based on a mixed open-closed-loop complementary filtering combined with a Rauch-Tung-Striebel (RTS) smoothing is suggested. Different types of varying-lag smoothing rules are examined. For near real-time applications, smoothing is applied to the data in a step-wise manner. The intervals (steps) for the smoothing are determined based on measurement availability and covariance and timing thresholds. For complete off-line processing, full data set smoothing is examined. Finally, the consequences of the smoothing and the open-closed-loop filtering are quantified based on real data. The impact of the smoothing throughout the steps is illustrated and the accuracy of the state estimates over the step is assessed.

KEYWORDS: Smoothing, inertial navigation, zero-velocity-update, complementary filtering.