

STUDIES ON OPTIMAL PLACEMENT OF MULTIPLE INERTIAL SENSORS FOR IMPROVING SENSING ACCURACY

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Abstract

Inertial Navigation Systems (INSs) are crucial self-contained systems utilized in military, aviation, and aerospace applications to provide uninterrupted Position, Velocity, and Attitude (PVA) information. These systems rely on Inertial Measurement Units (IMUs), typically comprising three orthogonal accelerometers and gyroscopes, to ensure reliable and robust performance. To address sensor malfunctions and enhance system reliability, Redundant Inertial Measurement Units (RIMUs) have been widely adopted, offering improved sensing accuracy and uninterrupted operation. Fault Detection and Isolation (FDI) in redundant sensor systems plays a vital role in achieving optimal performance. Additionally, sensor configuration significantly impacts the sensing accuracy and hence the navigation performance, and various methods have been explored to determine optimal configurations.

This Ph.D. thesis addresses key challenges in optimizing sensor configurations for redundant inertial sensors. Firstly, we propose a novel algorithm based on the MM (Majorization-Minimization or Minorization-Maximization) principle to determine the optimal orientation of multiple single-axis inertial sensors, considering varying accuracies. Existing research has mostly considered sensors with equal accuracies and uncorrelated noise. Numerical simulations validate the algorithm's effectiveness, demonstrating improved sensing accuracy for practical applications.

The presence of correlated measurement noise in inertial sensors introduces additional complexities in achieving optimal sensor configurations. Correlated noise arises when noise in one sensor is related to noise in another sensor due to common mode noise or shared environmental factors. To address this issue, we propose iterative algorithms based on the MM principle to solve optimization problems with a general noise covariance matrix. These algorithms offer an effective means to determine optimal configurations when correlated measurement noise is present.

To enhance sensing accuracy, a common approach involves adding additional sensors to existing configurations. We present an approach that preserves the initial sensor configuration while determining optimal orientations for appended sensors. This approach is particularly useful when redesigning the entire configuration is impractical or undesirable. Our method accommodates

sequential appending and considers sensors of different accuracies and correlated noise, providing a generalized approach for appending sensors.

Lastly, the thesis addresses the importance of sensor allocation and orientation in achieving an optimal configuration for RIMUs. Poor sensor allocation can lead to the huge lever arm effect (caused by deviations between the center of the RIMU and individual sensors' centers), causing errors in linear acceleration estimation and compromising system accuracy. We formulate the problem of optimal sensor allocation as an optimization problem and propose a numerical approach to determine the optimal allocation of sensors or lever arm vectors. Our approach considers sensors of varying sizes and addresses symmetric, asymmetric, and random configurations, contributing to the development of accurate and reliable navigation systems.

In conclusion, this thesis addresses critical aspects of optimizing sensor configurations for redundant inertial sensors. It introduces novel algorithms, addresses optimal configuration for varying accuracies and correlated measurement noise, explores appending sensors, and emphasizes the significance of sensor allocation. The proposed algorithms and methods offer valuable insights into achieving optimal sensing accuracy and thus maximizing the navigation performance. The findings contribute to advancements in inertial navigation technology and pave the way for the development of more accurate and efficient navigation systems.