

Distributed State Estimation for Sensor Networks under Adverse Communication Conditions

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論 文 内 容 の 要 旨

This thesis studies the problem of distributed state estimation in sensor networks, especially in harsh environments where communication links are unreliable and sensor data may be attacked. Achieving accurate and consistent state estimation in such scenarios is crucial for practical applications such as monitoring, control, and decision making. To address these issues, this work introduces three novel distributed filtering algorithms that improve estimation performance while tolerating packet loss and deceptive information.

The first proposed filter aims to reduce the estimation error caused by random packet loss. Unlike traditional methods that highly rely on complete data exchange, this filter allows each sensor to update its local estimate in the absence of partial data by fusing its own innovations with innovations from its neighbors. This design enhances information diversity and improves estimation accuracy, and is suitable for sensor networks with unstable communication links.

The second filter focuses on achieving more consistent estimates across sensors under high packet loss rate. It uses a structured fusion algorithm where each node shares both predicted and measured values to its neighbors. The fusion process is divided into two steps: the first step fuses the innovation terms and the second step fuses the consensus terms. These two parts are then combined to form an updated estimate. This hierarchical fusion design can better utilize partially available neighbor data and ensure that the sensor estimates remain close in time even when communication is only partially successful.

The third filter addresses the issue of deception attacks, where some of the transmitted data may have been intentionally altered. Instead of detecting which specific data points are false, this algorithm removes reliance on binary attack indicators by introducing an upper bound on the estimation error covariance. This upper bound is obtained through theoretical derivation and ensures the effectiveness of the update step even when tampered data is included. In addition, the method eliminates the need to propagate cross-covariance, thereby reducing computational complexity and improving the robustness of the system when the attack source cannot be identified.

The first proposed filter is supported by theoretical analysis, which proves its accuracy, stability and consensus. The effectiveness of all three filters is also verified by simulations of multiple dynamic systems, including mechanical systems, thermal systems, hydraulic systems, and electrical models. The results show that the first and second filters outperform the existing distributed filters in the case of frequent communication failures, while the third filter achieves robust estimation performance without identifying the attacked data.

In summary, this thesis proposes a series of practical and robust distributed filtering algorithms to provide solutions for achieving real-time estimation in unreliable or insecure sensor networks. These research results lay the foundation for the future research and deployment of distributed systems in critical applications.