Distributed Estimation in Wide-Area Camera Networks

(Research Statement) [Link: Video Summary]

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1. Introduction

The technology of smart sensing and communicating devices are advancing rapidly making such devices smaller, cheaper and more energy efficient. This enables the use of multiple sensor nodes, capable of communicating with each other, to perform complicated tasks which are otherwise hard to perform using a single sensor. Multiple sensors can cover more area, provide views from different angles and the fusion of all their measurements may lead to robust scene understanding. Due to this reason, networks of sensors are being used in many applications nowadays. For example, large-scale camera networks are being used for wide-area surveillance, disaster response, environmental monitoring, etc.

Among different information fusion approaches, distributed schemes are often chosen over centralized approaches due to their scalability to a large number of sensors, ease of installation and high tolerance to node failure. Most distributed state estimation schemes in the literature assume that each node can directly observe the target. For certain application scenarios e.g., when the sensors have limited FOV (e.g. a camera network), this assumption may not be true. My doctoral research has been focused on *the development of efficient theoretical frameworks for distributed state estimation (DSE) in a sensor network addressing the issue that* ***neighboring nodes may not be observing the same set of targets***. One of its applications is in the tracking of multiple targets in a wide area camera network without requiring a centralized processing unit. This research problem can be broken down into two parts i.e., distributed state estimation for a single target and distributed data association for multiple targets.

2. Distributed State Estimation: Single Target

Consensus algorithms are one of the many types of distributed algorithms which rely on peer-to-peer communication between neighboring nodes. The *Average Consensus algorithm* is a popular distributed algorithm which can asymptotically compute the average of some quantities in a network of agents in an iterative manner, without requiring all-to-all communication. DSE frameworks have previously been proposed based on distributed averaging of the local state estimates at different nodes. However, when some nodes do not have direct access to measurement information (such nodes are termed as *naive* nodes), their state estimates usually become poor (lack information). Incorporating naive nodes' state estimates in the averaging process can have detrimental effects in the DSE framework.

2.1. The Generalized Kalman Consensus Filter (GKCF)

To address the issue of naivety, as a preliminary work, we proposed the Generalized Kalman Consensus Filter (GKCF) [1] algorithm. The GKCF algorithm runs a separate consensus on the quality (inverse of the state covariance matrices) of their state estimates in parallel to the consensus on their state estimates. By doing so, it is possible to compute the weighted average of the state estimates in a distributed manner and this accounts for the issue of naivety. Simulation results show that the GKCF algorithm performs much better than the previously existing DSE algorithms, especially in the presence of naive nodes.

2.2. Information Weighted Consensus Filter (ICF)

Although the GKCF algorithm performs significantly better than pre-existing DSE approaches, the estimate it converges to (through consensus) is sub-optimal. This is mainly due to the reason that GKCF does not account for the cross-correlation between the state estimates at different nodes. To account for this issue, we proposed the Information Weighted Consensus Filter (ICF) [2] algorithm which is theoretically proved to converge to the optimal centralized Kalman filter estimates over multiple consensus iterations. Thorough synthetic experiments [4] on many different aspects revealed that ICF outperforms GKCF and other pre-existing approaches while also converging faster (better estimation accuracy is achieved using the same amount of communication and computational resource). This is a very important issue as modern sensors networks usually consist of low-powered wireless devices. ICF is based on the idea that with multiple consensus iterations, the state estimates at different nodes converge to the same value i.e., statistically, they become highly correlated. ICF utilizes the fact of high correlation between the state estimates of different nodes in its estimation framework.

3. Distributed State Estimation: Multiple Targets

For the state estimation of multiple targets, the knowledge of data association is required and to resolve the data association, the state estimates of all the targets are required. Moreover, the estimation errors in both of these processes have to be accounted for in both the processes.

3.1. Multi-target Information Consensus (MTIC)

To resolve both the data association and state estimation problem in an integrated and distributed fashion, we proposed the Multi-target Information Consensus (MTIC) [3] algorithm. The distributed data association portion in MTIC is based on the Joint Probabilistic Data Association Filter (JPDAF) algorithm and the distributed state estimation portion is based on the ICF algorithm that we derived earlier. In the presence of false measurements/clutter, hard data association schemes e.g., nearest neighbor based association approaches completely fail whereas probabilistic data association schemes such as JPDAF performs with great robustness. Inherited from the JPDAF algorithm, the MTIC algorithm is very robust to clutter.

4. Real-life Experiments

Real-life experiments were performed on actual multi-camera data-sets performing distributed tracking and distributed action recognition [5] using preliminary algorithms. Extensive real-life experiments on our most recent algorithms i.e., ICF and MTIC are yet to be done and we hope to accomplish that in the near future.

References

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