Trust Based Distributed Filtering

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PROBLEM DESCRIPTION

We a consider distributed state estimation of a linear dynamic systems, observed by various sensors, as a problem in information fusion.

We introduce a model of trust, using weights on the graph links and nodes that represent the sensor network. These weights can represent several interpretations of trustworthiness in sensor networks.

We show that by appropriate use of these weights the distributed estimation algorithm avoids using information from untrusted sensors

MODEL

We consider a sensor network with N sensors, indexed by i. The network is used for the state estimation of a linear random process given by:

$$x(k+1) = Ax(k) + w(k)$$

where $x \in \mathbb{R}^n$ is the state vector and $w \in \mathbb{R}^n$ is the state noise, assumed zero mean and with covariance matrix Q. The initial state x_0 has a Gaussian distribution, with mean μ_0 and covariance matrix P_0. We assume each sensor has a linear sensing model given by:

$$y_i(k) = C_i(k)x(k) + v_i(k)$$

where $y_i \in \mathbb{R}^{p_i}$ is the observation of $x(k)$ made by sensor i and $v_i \in \mathbb{R}^{p_i}$ is the measurement noise assumed Gaussian with zero mean and covariance matrix R_i. Let $\mathcal{N}_i$ denote the communication neighborhood of node i and let T_{ij} represent a measure of the trust sensor i has in the information received from sensor j.

References

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ALGORITHM AND SIMULATIONS

Algorithm 1: Trust Based Distributed Kalman Filtering Algorithm

Input: μ_0, P_0

Initialization: $\xi_i = \mu_0$, $P_i = P_0$

while new data exists

Compute the intermediate Kalman estimate of the target state:

$$\begin{aligned} M_i &= P_i^{-1} + C_i' R_i^{-1} C_i \\ L_i &= M_i C_i R_i^{-1} \\ \varphi_i &= \xi_i + L_i(y_i - C_i \xi_i) \end{aligned}$$

Compute locally the belief divergence:

$$d_{ij} = \frac{1}{\mathcal{N}_i - 1} \sum_{k \in \mathcal{N}_i} \|\varphi_j - \varphi_k\|^2$$

Compute the trust values:

$$T_{ij} = c_i - d_{ij},\ j \in \mathcal{N}_i$$

Compute the normalized trust values:

$$p_{ij} = \frac{T_{ij}}{\sum_k T_{ik}}$$

Eliminate insufficiently accurate data by setting T_{ij} to zero if $p_{ij} < p_i^{min}$

Compute the consensus weight values:

$$w_{ij} = \frac{T_{ij}}{\sum_k T_{ik}}$$

Estimate the state after a consensus step:

$$\hat{x}_i = \sum_{j \in \mathcal{N}_i \cup \{i\}} w_{ij} \varphi_j$$

Update the state of the local Kalman filter:

$$\begin{aligned} P_i &= A M_i A' + Q \\ \xi_i &= A \hat{x}_i \end{aligned}$$

We consider a perturbed oscillatory linear system:

$$x(k+1) = Ax(k) + w(k)$$

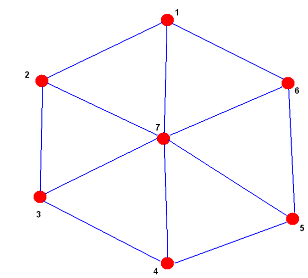
where,

$$A = \begin{pmatrix} 0.9996 & -0.03 \\ 0.03 & 0.9996 \end{pmatrix}$$

and $w(k) \in \mathbb{R}^2$ is a white, Gaussian noise, with covariance matrix $Q = 0.15 I_2$. Each sensor has a sensing model of the form:

$$y_i(k) = C_i x(k) + v_i,$$

where the observation matrices C_i are chosen at random to be $[0, 1]$ or $[1, 0]$ with the same probability. The measurement noise $v_i(k) \in \mathbb{R}$ is assumed white and Gaussian with variance $R_i = \sigma_v \sqrt{i}$ and $\sigma_v = 30$.



We consider a scenario involving seven sensors, where the centered sensor send false information.

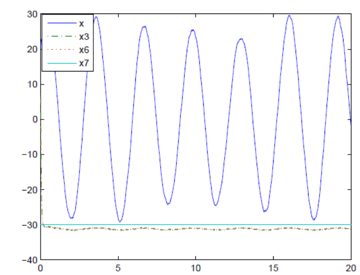


Fig. 1 - Distributed Kalman filtering with constant false information sent by sensor seven and no trust mechanism (x – true state, x1, x3, x6 – state estimates).

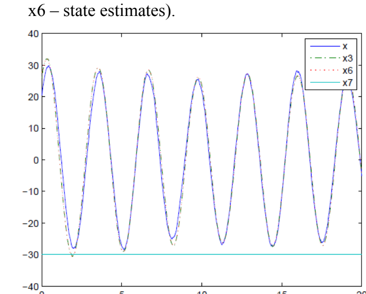


Fig. 2 - Trust based Distributed Kalman filtering with constant false information sent by sensor (x – true state, x1, x3, x6 – state estimates).