Distributed Fusion Estimation for Sensor Networks with Communication Constraints

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Preface

Advances in micro electromechanical systems and wireless technologies have allowed for the emergence of inexpensive micro-sensors with embedded processing and communication capabilities. A wireless sensor network (WSN) is a collection of these physically distributed micro-sensors communicating with one another over wireless links. In their various shapes and forms, the WSNs have greatly facilitated and enhanced the automated, remote, and intelligent monitoring of a large variety of physical systems and have found applications in various areas, such as industrial and building automation; environmental, traffic, wildlife, and health monitoring; and military surveillance. The purpose of a WSN is to provide users access to the information of interest from data gathered by spatially distributed sensors. In most applications, users are interested in a processed data that carries useful information of a physical plant rather than a measured data contaminated by noises. Therefore, it is not surprising that signal estimation, especially the multisensor fusion estimation, has been one of the most fundamental collaborative information processing problems in WSNs. The WSN, as a typical multisensor system, has greatly extended application areas of multisensor information fusion estimation, which was originally developed for military applications, such as target tracking and navigation. Although WSNs present attractive features, challenges associated with communication constraints, such as the scarcity of bandwidth and energy, as well as the delays and packet losses, in wireless communications have to be addressed in the WSN-based information fusion estimation and have attracted increasing research interest during the past decade.

This book provides the recent advances in distributed multisensor fusion estimation methods for WSNs with communication constraints, including the energy constraint, bandwidth constraint, communication delays, and packet losses. First, a review on the latest developments in the literature is presented in Chap. 1. Then, two energy-efficient fusion estimation methods, namely, the *transmission rate* method and the *packet size reduction* method, are introduced for sensor networks with energy constraints in Chaps. 2, 3, 4 and 5. Specifically, by slowing down the sampling and estimation rates, a multi-rate fusion estimation method is presented in Chap. 2 for sensor networks, where the sampling rate and the estimation rate are allowed to be different from each other and are parameters that can be designed to meet the energy constraints. In Chap. 3, a distributed state fusion estimation method is presented for sensor networks with nonuniform estimation rates, where the estimation rates among the various local estimators are allowed to be nonuniform and different from each other, that is, each local estimator is allowed to generate local estimates independently with an adjustable rate according to its power status. In Chap. 4, a distributed H_∞ fusion estimation method is introduced for sensor networks with nonuniform sampling rates, where the sampling rate of each sensor is allowed to be nonuniform and can be adjusted according to the sensor's power status. The energy-efficient fusion estimation method based on *packet size reduction* is introduced in Chap. 5, where a dimension reduction method is presented to reduce the size of packets containing the local estimates to be transmitted to the fusion estimator. The bandwidth constraint problem is considered in Chaps. 6 and 7. Specifically, a distributed H_∞ fusion estimation method is presented for sensor networks with quantized local estimates in Chap. 6. In Chap. 7, a hierarchical structure is presented for multisensor fusion estimation systems to reduce the communication burden of the fusion center. The communication uncertainties, including the delays and packet losses, are considered in Chaps. 8 and 9. Specifically, the fusion estimation for sensor networks with communication delays is introduced in Chap. 8, while the fusion estimation with both delays and packet losses is presented in Chap. 9.

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Contents

Symbols and Acronyms

$\Re$	Field of real numbers
$\Re^n$	n-Dimensional real Euclidean space
$\Re^{m\times n}$	Space of all $m \times n$ real matrices
I	Identity matrix
$\mathbf{0}$	Zero matrix
$A > 0$	Symmetric positive definite
$A \geqslant 0$	Symmetric positive semi-definite
$A < 0$	Symmetric negative definite
$A \leqslant 0$	Symmetric negative semi-definite
A^{T}	Transpose of matrix A
A^{-1}	Inverse of matrix A
$[a_{ij}]$	A matrix composed of elements a_{ij}, $i, j \in N$
$\mathrm{col}\{x_i\}_{i\in\phi}$	A column vector composed of elements x_i, $i \in \phi$
$\mathrm{Var}(x)$	Variance of the random vector x
$\mathrm{rank}(A)$	Rank of matrix A
$\rho(A)$	Spectral radius of matrix A
$\lambda_{\max}(A)$	Maximum eigenvalue of matrix A
$\lambda_{\min}(A)$	Minimum eigenvalue of matrix A
$\mathrm{Tr}(A)$	Trace of matrix A
$x \perp y$	Orthogonal vectors x and y
$\mathrm{proj}\{\cdot\}$	Projection operator
$\mathscr{L}(x_1, x_2, \ldots)$	Linear span of the vectors $x_1, x_2, \ldots$
$\mathrm{diag}\{\cdots\}$	Block-diagonal matrix
$\|\| \cdot \|\|$	Euclidean norm of a vector and its induced norm of a matrix
sup	Supremum
inf	Infimum
$\mathscr{L}_2[0, \infty)$	Space of square integrable functions on $[0, \infty)$
$l_2[0, \infty)$	Space of square summable infinite sequence on $[0, \infty)$
$\mathrm{Prob}\{x\}$	Probability of x
$\mathbf{E}\{x\}$	Expectation of x
$\mathrm{Var}(x)$	Variance of x, i.e., $\mathrm{Var}(x) = \mathbf{E}\{xx^{\mathrm{T}}\}$

WSN	Wireless sensor network
KF	Kalman filter
FC	Fusion center
MSE	Mean square error
LMI	Linear matrix inequality
BRL	Bounded real lemma
LTI	Linear time-invariant