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Estimation, filtering and fusion for networked systems with network-induced phenomena: New progress and prospects☆

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ABSTRACT

In this paper, some recent advances on the estimation, filtering and fusion for networked systems are reviewed. Firstly, the network-induced phenomena under consideration are briefly recalled including missing/fading measurements, signal quantization, sensor saturations, communication delays, and randomly occurring incomplete information. Secondly, the developments of the estimation, filtering and fusion for networked systems from four aspects (linear networked systems, nonlinear networked systems, complex networks and sensor networks) are reviewed comprehensively. Subsequently, some recent results on the estimation, filtering and fusion for systems with the network-induced phenomena are reviewed in great detail. In particular, some latest results on the multi-objective filtering problems for time-varying nonlinear networked systems are summarized. Finally, conclusions are given and several possible research directions concerning the estimation, filtering, and fusion for networked systems are highlighted.

1. Introduction

The networked systems have attracted increasing research attention due to their successful applications in a wide range of areas, such as aircraft, space and terrestrial exploration, access in hazardous environments, factory automation, remote diagnostics and troubleshooting, automated highway systems, unmanned aerial vehicles, manufacturing plant monitoring and condition-based maintenance of complex machinery [1]. The advantages of the usage of networked systems include flexible architecture, the reduction of installation and maintenance costs, decreasing the implementation difficulties and so on. However, the network-induced phenomena arise inevitably due to the insertion of the communication network with limited communication capacity [2–5]. Such network-induced phenomena include, but are not limited to, communication delays, missing/fading measurements, signal quantization, sensor saturations, variable sampling/transmission intervals, and out-of-sequence-measurement updates. Recently, a class of newly emerged network-induced phenomena (randomly occurring incomplete information) has gained some initial research interest in signal processing and control areas. Note that the network-induced phenomena could greatly degrade the performance of the networked systems and may even lead to the instability of the controlled systems [6,7]. Consequently, it is not surprising that both analysis and synthesis problems for networked systems have received considerable research attention in the past decade.

The filtering problem has long been one of the foundational research problems in signal processing and control engineering [8–12]. The past two decades have witnessed the rapid developments and extensive applications of the filtering algorithms in practice, such as guidance, navigation, target tracking, remote sensing, image processing, econometrics, and monitoring of manufacturing processes. Therefore, the design of the filtering algorithms has received increasing research attention. According to different performance indices (minimized variance constraint, set-valued constraints, guaranteed H_∞ performance requirements and so on), a great number of filtering algorithms have been developed for networked systems, such as Kalman filtering [13,14], extended Kalman filtering [15–18], set-valued filtering [19,20], set-membership filtering [21], H_2 filtering [22–24], H_∞ filtering

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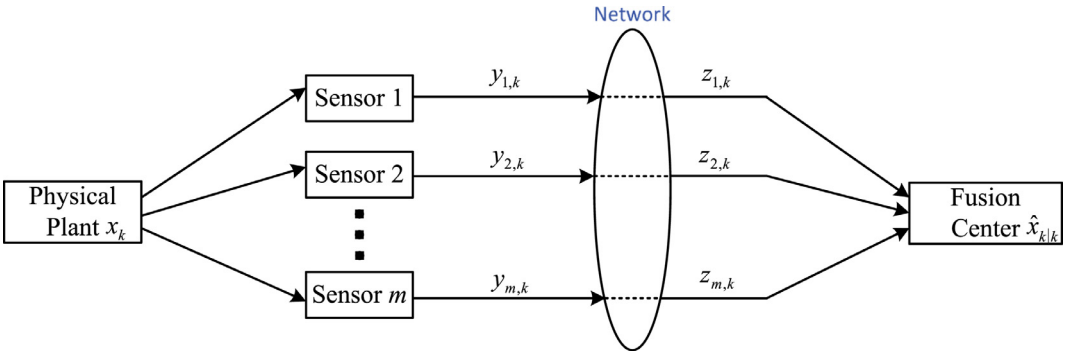

Fig. 1. Schematic structure of centralized fusion over network.

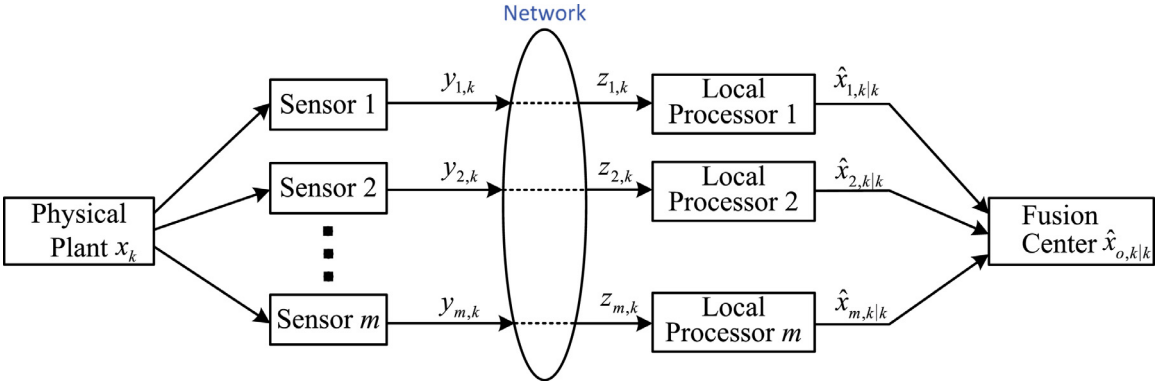

Fig. 2. Schematic structure of distributed fusion over network.

[25,26], and consensus filtering [27,28]. On the other hand, the design of linear optimal estimators (including filter, predictor and smoother) for networked systems has gained a great deal of research attention as conducted in [29–32].

On another research frontier, it is well known that the data fusion techniques can provide the fusion schemes by combining the information from different sources so as to achieve a satisfactory performance. Over the past decades, the data fusion techniques have been successfully applied in a variety of areas such as the target tracking, navigation, detection, robotics, video and image processing, business intelligence, and sensor networks. Therefore, considerable research effort has been devoted to the multi-sensor data fusion problems for complex dynamical systems. In fact, as mentioned in [33], there are a great number of challenging issues in the multi-sensor data fusion fields including data imperfection, outliers and spurious data, conflicting data, data modality, data correlation, data association, data alignment/registration, processing framework, operational timing, static versus dynamic phenomena, data dimensionality and so on. For more information about the challenging problems of the multi-sensor data fusion, we refer the readers to the survey paper [33] where more comprehensive interpretations have been provided. In what follows, we confine the addressed topic to the multi-sensor data fusion for networked systems and endeavor to introduce some recent advances on the network-based multi-sensor data fusion approaches from the perspective of algorithm developments. The multi-sensor data fusion algorithms can be generally classified into two types: centralized fusion and distributed fusion algorithms, where the schematic diagrams of centralized and distributed fusions in network environment are given as in Figs. 1 and 2, respectively. We will further discuss the recent developments of the multi-sensor fusion of networked systems later.

In this paper, we aim to provide a timely review on the recent advances of the estimation, filtering and fusion algorithms for networked systems with network-induced phenomena. The addressed network-induced phenomena include missing/fading measurements, communication delays, signal quantization, sensor saturations, randomly occurring uncertainties, randomly occurring nonlinearities, randomly occurring signal quantization, randomly occurring sensor saturations and so on. The recent developments of the network-induced phenomena are firstly discussed. Secondly, we review the analysis and synthesis problems of the networked systems from four aspects, including linear networked systems, nonlinear networked systems, complex networks and sensor networks. In the same section, several estimation, filtering and fusion schemes for networked systems are surveyed in great detail. Thirdly, latest results on estimation, filtering and fusion approaches for networked systems with network-induced phenomena are reviewed. Finally, conclusions are drawn and some possible research directions are pointed out.

The remainder of this paper is organized as follows. In Section 2, the network-induced phenomena are discussed. In Section 3, the developments of the estimation, filtering, fusion problems for networked systems are summarized. In Section 4, some latest results on the estimation, filtering and fusion problems for complex dynamical systems with network-induced phenomena are reviewed. Both conclusions and some future research topics are provided in Section 5.

2. Network-induced phenomena

Over the past decade, a great deal of research attention has been received regarding the modeling and analysis of the network-induced phenomena including missing/fading measurements, signal quantization, sensor saturations, communication delays, variable sampling/transmission intervals, out-of-sequence-measurement updates, randomly occurring incomplete information etc. Accordingly, many important approaches have been given