SOME PROGRESS IN SENSOR NETWORK DECISION FUSION

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Abstract The multisensor network decision/detection problem continue to attract much research interest in recent years since such system offers many advantages over that with a single sensor in terms of e.g., survivability, reliability, and robustness. This article surveys some previous progress, briefly presents a few new results, and proposes some challenging issues in communication direction of sensor network decision fusion.

Key words Communication direction, multisensor network, optimal fusion rule, optimal sensor compression rule.

1 Introduction

Distributed decision problem continues to attract much research interest, as evidenced by recent publications such as [1–12]. This is because a system with multiple sensors has many advantages over one with a single sensor such as the increase in the reliability, robustness and survivability of the system[3–5].

Consider the following distributed system. Each local sensor observes data and possibly a number of compressed binary messages (information bits) from other sensors simultaneously; it locally fuses/compresses all its data and received messages, which are then transmitted to other sensors; finally, the sensor at the top level node (i.e., the fusion center) in the network makes a final decision by combining all the received information using some fusion (final decision) rule in terms of an objective function. Communications between each sensor and the fusion center as well as among sensors are permitted. These networks are of a parallel, tandem, or their hybrid-tree-topology and thus are more general than those considered in [1, 2], formulated in [5, 6], and reviewed in [7, 8].

To optimize the performance of the system globally, it is customarily to find an optimum fusion rule from all possible fusion rules (see the formulation in [1, 3, 9, 10]) and then determine the corresponding set of optimal local sensor compression rules under a given communication pattern. Usually, to evaluate the merits of two different fusion rules, we determine the two corresponding sets of optimal sensor rules and then compare the two final costs. However, the number of possible fusion rules increases exponentially with the number of sensors or the number of bits received by the fusion center. An exhaustive method obviously is computationally
intractable. To the authors’ knowledge, however, there has been hardly any theoretical result on how to find a globally optimum fusion rule more efficiently.

On the other hand, a major constraint in sensor network decision is the limited communication bandwidth. Therefore, in addition to the heavy computational burden to find an optimal sensor rules-sensor observation compression, and an optimal fusion rule, a significant issue is how to arrange available communication quantity and communication direction among sensors. So far, there has been no any rigorous analytic result on the performance analysis of communication pattern between sensors in the existing literature. An intuitive idea is higher compressing observation of the sensor with higher noise power than compressing observation of the sensor with lower noise power, i.e., the sensor with higher noise power transmitting less bits and the sensor with lower noise power transmitting more bits. When the signal and sensor noises are both Gaussian, under some conditions some numerical examples were given in [3, 9, 10], which showed that the direction of communication does affect the performance of the distributed decision system significantly. Those numerical results seem consistent with the above intuitive idea.

In this article, we will survey our major progress in the optimization of sensor rules and fusion rule in the past a few years, and present a rigorous performance analysis of communication direction between sensors with different noise powers for a two-sensor tandem Bayesian binary decision system, which shows that the analytic result in some case is not consistent with above intuitive idea.

2 Models of Sensor Networks Decision

In this section, we consider two types of elementary distributed decision systems: parallel and tandem. Then, combining the both yields a hybrid network: tree system. These were all proposed in [5, 6].

2.1 Parallel Network

The parallel network is a basic information structure of a distributed decision system. We consider a distributed decision problem with \( m \) hypotheses, \( H_0, H_1, \ldots, H_{m-1} \), and \( l \) sensors, \( S_1, S_2, \ldots, S_l \), with multiple observation data \( y_1, y_2, \ldots, y_l \) in space \( R^{n_1} \times R^{n_2} \times \cdots \times R^{n_l} \). A set of local compression rules, \((I_1(y_1), I_2(y_2), \ldots, I_l(y_l))\), where

\[
I_i = I_i(y_i) = I_i^{(r_i)}(y_i) = (I_i^{(1)}(y_i), I_i^{(2)}(y_i), \ldots, I_i^{(r_i)}(y_i)),
\]

compresses data \( y_i \) to \( r_i \) information bits at each sensor \( S_i \) \((i \leq l)\). Then the local sensors transmit their compressed binary messages

\[
I_1(y_1) : R^{n_1} \rightarrow \{0, 1\}^{r_1},
I_2(y_2) : R^{n_2} \rightarrow \{0, 1\}^{r_2},
\ldots
I_l(y_l) : R^{n_l} \rightarrow \{0, 1\}^{r_l}
\]

to a fusion center \( \mathcal{F} \). Let notation \((r_1 + r_2 + \cdots + r_l)\) stand for the above sensor transmission pattern and \( N = \sum_{i=1}^{l} r_i \) be the total information bits. Upon the receipt of the local message (an \( N \) tuple), \( I = (I_1, I_2, \ldots, I_l) \), the fusion center \( \mathcal{F} \) makes a final decision under some fusion rule (see Fig. 1).