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Distributed interacting multiple model H_∞ filtering fusion for multiplatform maneuvering target tracking in clutter

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ABSTRACT

This paper deals with the problem of tracking a single maneuvering target from multiple platforms in the cluttered environment. A new solution based on H_∞ filtering is presented to relax the requirement of a prior knowledge of the noise statistics in the conventional Kalman filter. The contribution of this paper is twofold. First, the distributed H_∞ filtering fusion formulae for single model are developed. Second, in order to carry out distributed fusion within the multiple model framework, novel equivalent platform and global models are constructed using the best fitting Gaussian approximation approach so that the developed distributed fusion formulae can be applied directly in the fusion center. The effectiveness of the proposed algorithm is demonstrated through Monte Carlo simulations involving tracking of a highly maneuvering target in the three-dimensional (3D) experiment. The algorithm performs better in a simulated uncertain noise statistics scenario than the Kalman filtering counterpart.

1. Introduction

Multiplatform multisensor data fusion has been found a wide range of applications in diverse civilian and military areas such as local robot guidance [1] and global military theater defense [2]. In recent years there has been increasing interest on target tracking from multiple platforms [3–5] as multiple data sources can provide more information that is not available from individual sources. Furthermore, more robust performance can be obtained using multiple platforms due to the inherent redundancy [6].

The main purpose of multisensor data fusion is to obtain a joint estimate which is better than the individual sensor-based estimates. Many strategies have been proposed to resolve the fusion problem, of which Kalman filter is one of the most significant candidates. Two commonly used integration architectures, including centralized fusion and distributed fusion, have been widely studied for more than two decades [7–13]. Although the centralized architecture is theoretically optimal and it is also conceptually simpler to implement, the communication bandwidth should be high enough to send the measurements to the central unit and more computational costs are required. For the distributed fusion, which is also called as the state-vector or track fusion, a group of local Kalman filters are used in parallel to obtain individual sensor-based estimates and the distributed fusion formulae are then applied to yield an improved joint estimate. The major advantages of the distributed fusion are a reduced computational burden on the central processing unit and a lower communication loading along with parallel implementation. Moreover, the distributed fusion scheme obtains high fault-tolerant capability. Hence, the distributed fusion is preferable to centralized fusion in many practical situations [14,15]. To obtain the optimal estimates as those derived in the centralized fusion, two approaches are usually taken: distributed fusion with feedback [16] and distributed fusion without feedback [17].

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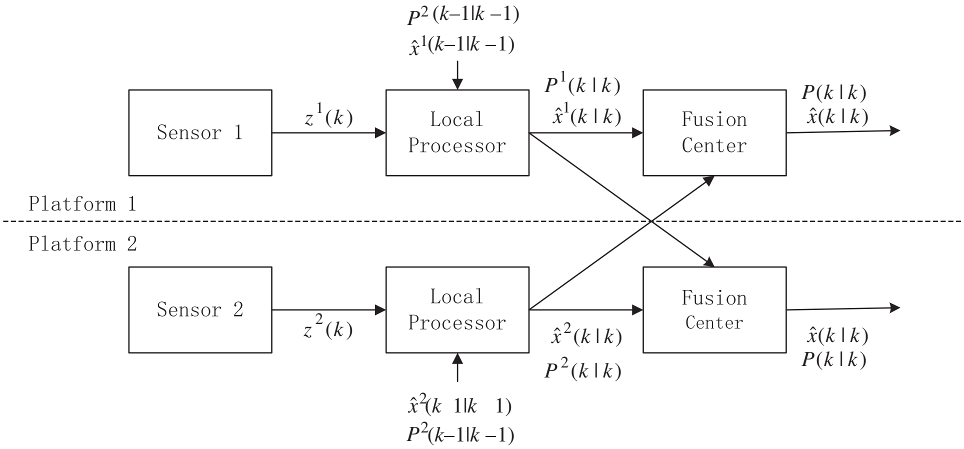

Fig. 1. The architecture of tracking system with two platforms.

For the multiplatform multisensor tracking system with distributed architecture, as shown in Fig. 1, each sensor receives the measurements to produce sensor-based estimates at the local processor which are then transmitted to the central unit (or fusion center) on each platform for fusion. In this case, both fusion units have identical fused estimates so that the feedback scheme can be implemented on each platform separately. In the target tracking community, the single model approach is used mainly for targets with fixed kinematic behaviors [18,19], while for targets with multiple kinematic behaviors (i.e., maneuvering targets), a multiple model algorithm is preferred. As one of the most cost-effective schemes for tracking maneuvering targets, the interacting multiple model (IMM) estimator [20] has been performed on local processors in the multiplatform tracking systems. The main challenge for multiple model fusion is that the propagations of the previously fused estimates are needed in the fusion formulae while they do not exist due to lack of a global model. To circumvent this problem, based on constructing equivalent platform and global models, distributed IMM fusion algorithms with and without multirate schemes are proposed in [21,22], respectively. The results are extended to develop a distributed interacting multipattern data association algorithm for tracking multiple maneuvering targets in [23]. It is noted that the equivalent single model is simply constructed by a weighted average of system matrices where the model probabilities in the IMM estimator are chosen as weights. Unlike the above-mentioned approach, novel equivalent models are proposed in this paper in the sense that the distribution of target state has the same mean and covariance under the original multiple model and the equivalent single model. Indeed, in most cases, the target tracking is performed in the cluttered environment where false measurements are presented and the target might not be detected [24]. An effective approach to solve the data association problem is that of probabilistic data association (PDA) for single target tracking which is used in this paper and that of joint probabilistic data association (JPDA) for multiple targets tracking [25].

It should be mentioned that the results of all the aforementioned papers for target tracking and data fusion are derived based on the Kalman filter and its variants [26], in which the statistics of the noise must be white and Gaussian with exactly known variances. These limitations, however, are too strong to be always satisfied in real applications. To overcome them, the H_∞ filter provides an alternative without requiring a prior knowledge of noise statistics but the only assumption made is that the noise signal has a finite energy. In addition, the H_∞ filtering aims at minimizing the worst possible effects of the unknown disturbances on the estimation errors and is more robust against the estimation errors and model uncertainties than Kalman filtering [27]. Although H_∞ estimation techniques have been studied in many fields such as active noise cancelation [28], signal reconstruction [29] and joint estimation of channel and symbols [30], little research has been done on target tracking [31,32].

This paper is aimed at resolving the problem of distributed H_∞ filtering fusion within the multiple model framework and its application for multiplatform maneuvering target tracking in the cluttered environment. The IMM H_∞ filter combined with the PDA technique is performed on each platform to derive sensor-based tracks. By developing the distributed H_∞ filtering fusion formulae and introducing novel equivalent platform and global models using the best fitting Gaussian approximation method, as shown in Fig. 2, the sensor-based tracks can be fused in the central units. Simulation results show better performance than that of the Kalman filtering fusion algorithm proposed in [22].

The remainder of this paper is organized as follows. The distributed H_∞ filtering fusion formulae for single model are developed in Section 2, followed by the fundamentals of multiplatform tracking such as the tracking model and the IMM-PDA filtering in Section 3. Section 4 develops a novel distributed IMM H_∞ filtering fusion algorithm. A simulation study for demonstrating the effectiveness of the proposed algorithm is presented in Section 5. Finally, some conclusions are drawn in Section 6.