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Intuitionistic fuzzy joint probabilistic data association filter and its application to multitarget tracking

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ABSTRACT

This paper proposes a new intuitionistic fuzzy joint probabilistic data association filter for multitarget tracking in a cluttered environment. In the proposed algorithm, the joint association probabilities in JPDAF are reconstructed by utilizing intuitionistic fuzzy membership degrees of the measurements belonging to the targets. To compute the intuitionistic fuzzy membership degree, a new intuitionistic fuzzy clustering method is proposed based on intuitionistic fuzzy point operator, which can extract useful information from uncertainty information of measurement. At the same time, two new weight assignments are introduced to deal with the uncertainty of measurement, which lead to two different data association methods, IF-JPDAF1 and IF-JPDAF2. Moreover, according to the characteristic of multitarget tracking, a new intuitionistic index of intuitionistic fuzzy set is defined. Finally, experiment results show the proposed algorithms have advantages over the conventional methods (including the JPDAF, Fitzgerald's JPDAF and MEF-JPDAF) in terms of efficiency and robustness.

1. Introduction

A key problem of multitarget tracking in a cluttered environment is that of measurement-to-track data association. When multiple targets are present, data association is the process of determining which measurements should be combined with the existing target tracks [1]. To solve the data association problem, many methods were proposed [2–5]. These can be broadly categorized as either single frame assignment methods, or multi-frame assignment methods [3]. This paper will mainly focus on the former here. The Nearest Neighbor Standard Filter (NNSF) associates each target with the closest measurement in the target space. However, this simple procedure prunes away many feasible hypotheses. Sathyan and Chin [4] proposed a multiple hypothesis tracking algorithm called Multiple Detection Multiple Hypothesis Tracker (MD-MHT) for tracking systems that generate multiple measurements for each target. However, the Multiple Hypotheses Tracker (MHT) attempts to keep track of all the possible association hypotheses over time. This is a NP-hard problem, since the number of association hypotheses grows exponentially over time. In this respect the Joint Probabilistic Data Association Filter (JPDAF) is more appealing [5]. At each time step, infeasible hypotheses are pruned away using a gating procedure. A filtering estimate is then computed for each of the remaining hypotheses, and combined in proportion to the corresponding posterior hypothesis probabilities. However, the JPDAF tends to coalesce neighboring tracks, and the calculation of joint probabilities in JPDAF seems complicated even if the used formulas are well established in probability theory.

Though the JPDA filter has many problems to the multitarget tracking, it is the best-known example of the Bayesian data association paradigm. From this point of view, JPDA seems to have a fundamental advantage over

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classical measurement to track association approaches (such as NN, MHT etc). Because of its appealing paradigm, JPDA has stimulated further developments, many of which have been directed to improving the stability or complexity of the numerical evaluation of the JPDA equations. These researches have led to the development of several suboptimal JPDA [6] and to the exact nearest neighbor version of the JPDA (ENNPDA) of [7]. Another suboptimal JPDA is Fitzgerald's ad hoc approach which seems to work well in some cases of crossing targets [8]. However, because the sum of association probabilities in Fitzgerald's approach is not equal to one, it will cause problems when used in multitarget tracking. Moreover, more fundamental studies have been directed toward the development of new approaches in approximating the conditional density. One direction is the approximation of the conditional density for each target's state by a reduced mixture of Gaussian densities [9], rather than by JPDA's single Gaussian. In [10], Chen et al. proposed an online clutter estimation technique to handle the nonhomogeneous clutter background based on the nonhomogeneous Poisson point processes. In addition, to regularize the clutter spatial intensity estimation problem, the Gaussian mixture model is used to represent the clutter spatial intensity function.

The methods mentioned above were mainly based on the framework of probability and statistics theory proposed. Nowadays, fuzzy mathematics has been widely applied to describe some uncertain knowledge or physics phenomena in non-linear complicated system [11,12]. Zhang and Ji [13] proposed a novel fast partitioning algorithm for the ETT-PHD filter, which substitutes the distance partitioning with a fuzzy ART model. Singh and Bailey [14] firstly proposed a fuzzy logic approach for the data association problem in multi-sensor multi-target tracking. Chen and Huang [15] proposed a data association algorithm based on fuzzy-logic called fuzzy data association (FDA) for radar/infrared sensor data fusion. Unfortunately, all the methods based on fuzzy logic mentioned above, the number of fuzzy rules grows exponentially with the number of targets, so the extension of these approaches to the case of large number of targets is fairly complex.

Actually, the data association problem can be regarded as a classified process of a validated measurement set. So many data association approaches based on fuzzy clustering have been proposed. Ashraf et al. [16] firstly applied fuzzy c-means clustering (FCM) algorithm to solve the data association problem for multi-sensor multi-target tracking. However, the performance of fuzzy logic data association approaches degrades drastically in case of a dense cluttered environment. Moreover, to solve the data association of multitarget tracking in a cluttered environment, many methods which combined the JPDAF algorithm with fuzzy c-means clustering were proposed. In [17,18], Ashraf proposed an all/nearest-neighbor fuzzy association approach for tracking multiple targets in a cluttered environment. Their approach has a similar form to joint probabilistic data association filter except that the probability weights are replaced by fuzzy weights. Oussalah and Schutter [19] proposed Hybrid Fuzzy JPDAF based on fuzzy c-means clustering algorithm for multitarget tracking. In their approach, a new noisy fuzzy c-means algorithm based on Dave's clustering approach was proposed to calculate the association probabilities in JPDAF. Unfortunately, in order to ensure eventual convergence to an optimal solution, the Hybrid Fuzzy JPDAF must adapt to adjust the cluster center through iteration, which make the algorithm have a heavy computational load and cannot applied to real time target tracking.

On the other hand, the maximum entropy fuzzy clustering widely applied to the data association of multitarget tracking. Liu and Meng [20] introduced an online data-driven Max-entropy fuzzy clustering algorithm to predict the trajectory of moving target in robotic tracking, which is very fast and efficient in terms of computational cost and suitable for real time environment. Li et al. [21] proposed a novel data association algorithm based on Max-entropy fuzzy clustering called Maximum entropy fuzzy-JPDAF (MEF-JPDAF) for multitarget tracking. Their algorithm defined a maximum validated distance based on discrimination factor that can effectively eliminate some invalidated measurements and reduce the computational load, and can be applied to real time target tracking. However, in order to reduce the computational load, the MEF-JPDAF eliminates many invalidated measurements, which can make their algorithm unstable in a dense cluttered environment. In [22], the maximum entropy fuzzy probabilistic data association filter was extended to track a bearings-only maneuvering target in a cluttered environment.

Recent years, intuitionistic fuzzy set (IFS) have been found to be very useful to describe and deal with vague and uncertain data [23]. For this reason, intuitionistic fuzzy set (IFS) has been widely used to various fields [24,25], such as fuzzy clustering, multiple attribute decision making, situation and assessment of threat of information fusion, etc. Xu and Wu [24] proposed an intuitionistic FCM (IFCM) algorithm based on the well-known fuzzy c-means clustering method and the basic distance measures between IFSs. Chaira [25] proposed a novel intuitionistic fuzzy c-means clustering method using intuitionistic fuzzy set theory. In their method, a new objective function based on intuitionistic fuzzy entropy is incorporated in the conventional fuzzy c-means clustering algorithm. Because the intuitionistic fuzzy set theory considers the uncertainty parameter of the hesitation degree that arises while defining the membership function, the cluster centers may converge to a desirable location than the cluster centers obtained using fuzzy c-means algorithm. Inspired form literatures [17,25], a novel intuitionistic fuzzy joint probabilistic data association filter is proposed in this paper. In the proposed method, in order to incorporate uncertainty information of measurement, a new intuitionistic fuzzy clustering method is proposed based on intuitionistic fuzzy point operator, and the joint association probabilities in JPDAF are reconstructed by utilizing intuitionistic fuzzy membership degrees of the measurements belonging to the targets. At the same time, two new weight assignments are introduced to deal with the uncertainty of measurement, which lead to two different data association methods, IF-JPDAF1 and IF-JPDAF2.

The rest of this paper is organized as follows. A brief introduction to multitarget tracking methods such as JPDAF, Fitzgerald-JPDAF is presented in Section 2. Section 3 discusses the proposed intuitionistic fuzzy joint probabilistic data association filters (IF-JPDAF1 and IF-JPDAF2).