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A joint possibilistic data association technique for tracking multiple targets in a cluttered environment

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ABSTRACT

Multitarget tracking in a cluttered environment is a significant issue with a wide variety of applications. A typical approach to address this issue is the joint probabilistic data association (JPDA) technique. This technique determines joint probabilities over all targets and hits and updates the predicted target state estimate using a probability-weighted sum of innovations. This paper proposes a new joint possibilistic data association technique for tracking multiple targets. Unlike the JPDA technique, the proposed technique determines joint possibilities over all targets and hits and updates the predicted target state estimate using a possibility-weighted sum of innovations. The possibility weights are determined using the noise covariance matrices and the current received measurements such that the total sum of the distances between all measurements and targets is minimized. The proposed technique performs data association based on a possibility matrix of measurements to trajectories; thus, it highly reduces the computational complexity compared to conventional data association techniques. The proposed association technique is applied to examples of multitarget tracking in a cluttered environment, and the results demonstrate its efficiency.

1. Introduction

Data fusion systems have important civilian and military applications [2,6,8–10,22,29,32,37,48,57,58]. One of the main issues with data fusion systems is multiple-target tracking [1,11,35,38,39,55]. Data association is an important issue when tracking multiple targets in the presence of false alarms or clutter [3–5,7,52,56]. Data association is applied in many practical systems such as wireless sensor networks [33,36,46], vehicle tracking [19], data mining [23,26,41], face recognition [31], meteorological data [17], dynamic images [60], and others.

Multiple-target tracking techniques include trajectory initiation techniques, trajectory maintenance techniques, and trajectory deletion techniques. We focus only on data association, which is the main task of trajectory maintenance techniques. There are other techniques in the literature to solve the problems of trajectory initiation and trajectory deletion [12–16].

Deciding from which target, if any, a received hit (measurement) originated is one of the most crucial issue in multitarget tracking systems. This is referred to as the data association process. Data association is a fundamental process in multitarget tracking systems. It is the process of deciding which of the received hits to use to update each target trajectory (track), i.e. it is responsible for partitioning the received hits into groups that could have originated from the same target trajectories. When tracking multiple targets, there is always uncertainty associated with the origin of the received hits, when there is

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a high false alarm, a low detection probability, a cluttered environment, or multiple targets in the same neighborhood. Hits can be in a wide variety of forms, such as x- and y-positions, range, bearing, etc. After performing data association, the estimate of the state for each target trajectory is updated with the associated target hits. Data association and state estimation have been the subjects of extensive study since the 1970s [13–17]. This is called hits-to-targets association for dynamic targets. In most real multitarget tracking problems, association of hits is performed solely on the basis of positional information.

There are two main categories of data association in multiple targets tracking: nearest-neighbor data association and all-neighbor data association. The nearest-neighbor data association category has two types of solutions: strongest neighbor filter (SNF) and nearest-neighbor filter (NNF) [12–16]. In these approaches, one hit, at most, can be used to update a given target trajectory. In the SNF, the signal with the highest intensity among the validated received hits is selected to update the target trajectory. In the NNF, the hit that is closest to the predicted target hit is the one selected. In nearest-neighbor data association approaches hits are assigned to existing trajectories in such a way as to minimize or maximize an overall correlation measure. A clear description of nearest-neighbor association techniques is provided in [16]. The performance of the nearest-neighbor association technique under many correlation measures is considered in many studies [28,53]. The optimum nearest-neighbor data association filter is presented in [12–14] by maximizing the likelihood of the residual error. The SNF and NNF techniques perform very well in the case of well-spaced targets with high signal-to-noise ratios and a clutter-free environment. However, they do not perform well in the case of closing targets with high false alarm rates or low detection probabilities [1,7,12,16].

The optimal solution of the multitarget association problem is the multiple hypothesis tracker (MHT) [12,16]. This is considered to be the theoretically optimum data association approach under idealized assumptions. The MHT addresses the multitarget association problem by evaluating the likelihood that there is a target given a number of hits. The output from the MHT is typically a list of hypotheses that can be arranged by their probability estimates. Unfortunately, the high computational complexity of MHT limits its practical implementation. In addition, a priori knowledge of the noise statistics is required. Therefore, suboptimal realization of the MHT has many potential pitfalls. For this reason, many tracking approaches have been developed which sacrifice performance for the sake of computational feasibility. Thus, the newly developed approaches are suboptimal but computationally feasible. The probabilistic data association (PDA) filter and the joint probabilistic data association (JPDA) filter were developed in [12] to solve the problem of data association in the case of multiple-target tracking. Instead of using only one hit among all the received and validated hits while discarding the others, the PDA and JPDA filters use all of the validated hits with different probability weights. The result is that the updated target trajectory may contain contributions from more than one hit, each with some correlation probability. The JPDA filter is identical to the PDA filter except that the correlation probabilities are computed using all hits and all trajectories. An approximation of the JPDA filter is proposed in [25] to reduce the required computations. This approximation highly degrades the performance in the case of a large number of hits and targets [61,62].

While the MHT is classified as a hard-decision multiscan association technique, the interacting multiple model joint probabilistic data association (IMMJPDA) is classified as a soft-decision zero-back scan association technique [7,47]. The IMMJPDA combines several trajectories in a probabilistic way to update each target state estimate [12,40]. This is one of the best association approaches, yielding a performance comparable to that of the MHT approach. There are other schemes for tracking multiple targets based on expectation maximization [13,14], the probability hypothesis density (PHD) filter [43], the particle filter [30,54], the Kalman-Levy filter [51], and the inverse gamma distributed texture [7,14]. The time-recursive multiple targets tracking approach, based on expectation maximization, achieves better performance compared to the JPDA technique at the expense of additional computations [1,7,15].

Neural networks and fuzzy logic approaches are considered approximate solutions to the problem of multiple targets tracking [18,20,24,27,45]. The disadvantages of neural network implementations are that they require a very large number of neurons and require training with an unreasonable number of trajectories. For example, a neural network scheme is presented in [36] to implement the JPDA approach. Due to the complexity of this scheme, it can handle only a small number of targets and hits (6 targets and 20 hits at most). In general, the number of neurons grows exponentially with the number of targets and the number of hits [1,34,49].

Fuzzy logic technologies are also used in multitarget tracking [5–7,42,44]. Fuzzy logic approaches for data association consist of four basic elements [1,3,4,7]: (1) fuzzification interface, which transforms the received sensor hits into fuzzy (linguistic) variables using some forms of membership functions; (2) fuzzy knowledge-base, which contains fuzzy logical statements in terms of fuzzy IF-THEN rules. The IF-THEN rules use linguistic terms (such as low, medium, and high) to incorporate ambiguity; (3) fuzzy inference engine, which employs fuzzy knowledge-base to generate fuzzy outputs; and (4) defuzzification interface, which transforms the fuzzy outputs (from the fuzzy inference engine) into non fuzzy outputs to obtain the final association decisions.

The disadvantages of fuzzy logic approaches are that they require a very large number of fuzzy IF-THEN rules and/or use iterative approaches. A fuzzy approach, based on the fuzzy clustering means (FCMs) algorithm, is proposed in [7]. It replaces the probability scores with fuzzy scores. The fuzzy scores are determined using a time-consuming iterative method, and the number of iterations depends on the initial values, the number of targets, and the number of measurements. In general, fuzzy logic solutions of the problem of multiple target tracking are approximate solutions. The accuracy of the solutions depends on the number of input variables, the choice of fuzzy functions, the number of linguistic variables, and the number of fuzzy statements and rules. In addition, the solutions of fuzzy logic approaches for multiple target data association and tracking are