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Measurement level AIS/radar fusion

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ABSTRACT

In maritime surveillance, messages from radar and the Automatic Identification System (AIS) receivers are used for vessel trafficking and monitoring. The common trend is to use radars as the primary source of surveillance and AIS as a secondary source with little interaction between these data sets. The AIS messages provide very accurate position estimates associated with ID and other vessel information. However, AIS messages arrive unpredictably and intermittently depending on the type and behavior of the vessel. In addition, the revisit interval of AIS messages could be very large and it may vary from one vessel to another.

In this work, a new measurement-level fusion algorithm to combine radar and AIS messages is proposed using the Joint Probabilistic Data Association (JPDA) framework. The proposed method handles AIS ID swaps between vessels and missing IDs while effectively fusing the radar measurements with AIS messages at measurement level. The uncertainty in the AIS ID-to-track assignment is resolved by assigning multiple AIS IDs to a target and updating the ID probabilities using a Bayesian inference with radar measurements, AIS messages and other targets. The performance of the proposed measurement-level fusion is compared with that of the track-to-track fusion. A modified Posterior Cramér-Rao Lower Bound (PCRLB) is also derived for the variable-rate heterogenous AIS/Radar network. Experimental results based on simulated data demonstrate the performance of the proposed technique.

1. Introduction

Due to the advances in sensor technology, a wide range of sensors such as radars, sonar and video are available for simultaneous deployment to monitor a specific region [23]. Furthermore, with the Automatic Identification System (AIS) [13,29] in maritime surveillance, Global Position System (GPS) enabled onboard transponders mounted on vessels broadcast the vessels' locations together with other vessel-specific information that can be picked by other vessels in the vicinity and ground or space-based AIS receivers [13].

Multiple sensor networks can be broadly categorized as homogenous (e.g., multistatic radar system, radar networks) in which case the observation from all sensors is mapped to the same measurement space [9], or heterogenous (e.g., AIS/radar surveillance system) where the observations are mapped into different kinematic and feature measurement spaces. Some representative feature measurements include target ID and type [27,33]. Each sensor could process the observation and report its track estimates in a distributed framework or forward the observations to a fusion center in a centralized framework [7]. With the centralized fusion architecture consisting of a heterogenous sensor network, diverse information from multiple sources can be effectively fused to yield a single combined estimate [7]. In general, the fused estimates

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from multiple sources can improve overall tracking performance with respect to estimation accuracy, number of false tracks and missed detections over the corresponding metrics with a single source [21].

One way of fusing information from multiple sensors is track-to-track fusion [1,4,5,9], where the fusion is done at the track level such that separate tracks are initiated and maintained at each senor and combined later at the fusion node. In a multitarget scenario, the track-to-track fusion is done in two steps: The first step is to determine if the tracks are from the same target while the second step is to combine the associated tracks to form a single estimate. In [4,5], track-to-track fusion based on Bayesian Minimum Mean Squared Error (MMSE) is presented for a homogenous sensor network. The optimal track-to-track fusion that effectively computes the cross-covariance between tracks of different sensors considering the common process noise is proposed in [9]. The performance limits of track-to-track fusion versus centralized estimation is further investigated in [10] and track-to-track fusion with heterogenous sensors is presented in [27,33]. An alternative approach to distributed tracking with Probability Hypothesis Density (PHD) Filter that uses Huffman coding technique to effectively encode and transmit a measurement set with false alarms is also proposed in [19].

Although track-to-track fusion is a computationally efficient approach, estimation error resulting from tracking at the local level and from the fusion at the global level accumulate over time and, as a result, the overall estimation errors may become large. In addition, there may be a processing delay in estimating tracks from each source before fusing and reporting the final confirmed track. Also, fusion performance may degrade due to miss-association across tracks from different sensors [11]. Another alternative to multisensor information fusion is measurement level fusion [14], where measurements from different sources are forwarded to the centralized fusion center and processed jointly by a measurement-to-track association algorithm to initialize and maintain tracks. In [18,20] the joint processing of measurements from multiple propagation modes and homogenous sensor network is handled as a multiple detection problem. In [32], a large scale air traffic surveillance problem using a centralized architecture is considered. Measurement level fusion usually offers improved tracking performance, over distributed tracking but with the need for more computational resources as well as sufficient bandwidth between the senors and the fusion center.

Information fusion with a heterogenous sensor network is often used for vessels tracking to form a common maritime picture [29]. In maritime environment radars are primarily used for surveillance near ports. Radars provide range and bearing measurements of the vessels in the vicinity. Also, vessels identify themselves intermittently by broadcasting their location information using the Automatic Identification System (AIS) [29]. The AIS messages include position estimates with GPS-level accuracy, rate of turn, course and speed. In addition, extra information such as destination, estimated time of arrival, vessel name and type can be included in the AIS messages. The original purpose of exchanging AIS information among nearby vessels was to avoid collisions and also to gather additional information for navigation and route planning as part of Maritime Domain Awareness (MDA) [13,29]. The transmission rate of AIS messages depends on the relative position of the vessel from the coastline and the type of vessels. A vessel's transponder could be intentionally turned off as well. Bandwidth sharing among vessels while transmitting messages make the AIS prone to message interference, conflicting AIS IDs and missing AIS IDs.

Due to the aforementioned limitations with the AIS framework, data availability depends on the type and behavior of the vessel as well as the receiver architecture (e.g., space or ground based). On the other hand, radars usually report measurements at a constant revisit interval although they are prone to large measurement errors, false alarms, missed detections and radar blind zones compared to AIS messages. In the literature, previous works mainly focus on track level fusion of radar and AIS measurements [8,12,16]. Track level fusion between the AIS data and Over-the-Horizon (OTH) radar was presented in [12].

In this paper, an algorithm for the measurement-level fusion of AIS messages and radar measurements is proposed based on the Joint Probabilistic Data Association (JPDA) [25] framework. Tracks are initialized based on radar measurements and are assigned to the list of AIS IDs based on the initial distributions. As a result, once the target is associated with the AIS ID its states can be updated with radar observations even if the ship is not transmitting AIS data. For targets that are widely separated, there will be no ambiguity in the AIS ID-to-track association. However, as vessels get close to one another, there will be ambiguity in AIS ID-to-track assignment. In addition, AIS ID ambiguity may result from intentional ID spoofing [13]. In order to resolve the assignment ambiguity, a probabilistic AIS ID-to-track assignment technique is proposed. As a result, each track keeps a list of AIS IDs with probabilities that are updated by Bayesian inference based on AIS messages, radar measurements and other tracks. In contrast, previous approaches assume that AIS ID information is perfect (i.e., no ambiguity). The proposed approach facilitates the handling of AIS ID swaps among vessels and AIS messages with missing IDs. In addition, without having to wait for local track confirmation as in the track-to-track fusion, the proposed measurement level fusion approach offers faster global track update and confirmation.

The effectiveness of the proposed measurement level fusion algorithm is compared with that of track-to-track fusion, which uses a Bayesian MMSE approach to fuse radar-only and AIS-only track estimates. Furthermore, the optimality of the proposed method is demonstrated by comparing with a modified Posterior Cramér-Rao Lower Bound (PCRLB) derived for the variable-rate heterogenous AIS/Radar network under various AIS revisit intervals and radar measurement errors. Computational complexity is also analyzed.

The rest of paper is organized as follows. In Section 2 mathematical models for target dynamics, radar measurements and AIS messages are presented. In Section 3, the AIS-only tracking based on the perfect ID assumption and Kalman filtering as well as radar-only tracking based on

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