Integrated Detection and Tracking in Multistatic Sonar

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ABSTRACT

An ongoing research effort at the NATO Undersea Research Centre (NURC) has included the development of multistatic sonar fusion and tracking technology for effective undersea surveillance. This paper summarizes the progress in this area, and identifies the sensor management tasks that are of current interest. In particular, we study the potential value-added of adaptive data thresholding based on feedback from the current surveillance picture.

1 TARGET TRACKING RESEARCH AT NURC

Due to the quiet nature of current threat submarines as well as the complexity of shallow-water acoustic environments, surveillance based on active sonar technology has received considerable attention in recent years. The use of surveillance networks with a number of source-receiver detection nodes provides a powerful framework for effective surveillance, as these provide multiple detection opportunities and robustness against unfavourable source-target-receiver geometries.

A number of requirements exist in order to explore the potential of active sonar surveillance networks. The first is the availability of prototype systems to acquire test data. Multistatic sonar surveillance scenarios are generally based on one of two system concepts: mobile platforms (suitable for expeditionary tasks), and fixed/drifting deployed fields (suitable for surveillance of ports, harbors, choke points, etc.). Both system concepts are under evaluation at NURC. A second requirement is the availability of signal and information processing technology that produces manageable sets of contacts for each ping-source-receiver triple, contacts that can be exchanged through radio or satellite links for further exploitation at a fusion center. This technology has been demonstrated in NURC sea trials, with both system concepts.

A third requirement for undersea surveillance, which is particularly critical in multi-sensor settings with a correspondingly sustained data rate, is the availability of an automated fusion and tracking capability. Typically, active sonar processing will produce hundreds of object-like contacts per ping-source-receiver triple. This may well lead to thousands of contacts per minute in a typical surveillance network. It is critical to extract from this voluminous data a small, manageable number of target-like tracks that are provided to a sonar operator for further analysis. This third requirement has been the focus of an ongoing research effort at NURC that was initiated in early 2002. This effort has leveraged the availability of mobile-platform and deployable-fields datasets and the corresponding contact-level data files (i.e. the first and second requirements noted above).

Key milestones in this research have included the following:

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- Development of statistically consistent measurement models for target contact data, to account for a variety of system and measurement errors [1], and application of these models to an analysis of intra-ping simplifying approximations and to sensor placement;
- Development of multistatic capabilities of increasing complexity and performance, with nearest-neighbor, multi-hypothesis, and distributed multi-hypothesis [2] data association;
- Development of centralized and distributed tracker performance models that account for target fading effects [3].

Current and future capability upgrades include Doppler-enhanced, classification-aided, and feature-aided tracking. Our most recent effort has been to evaluate the relative merits of centralized and distributed tracking and fusion architectures based on extensive processing of sea trial data. The results of this analysis are qualitatively consistent with our tracker performance models. In particular:

- Target tracking significantly improves the detection and localization performance of contact data; as such, it provides significant value added to the surveillance processing chain.
- With high detection redundancy and low FAR data, centralized and distributed multi-sensor tracking both outperform single-sensor tracking, and achieve comparable performance.
- As detection redundancy is lost and targets exhibit fading behavior (i.e. long detection / no-detection streaks), with low FAR data, distributed tracking outperforms centralized tracking. Indeed, the distributed tracker more effectively exploits single-sensor detection streaks.
- With high detection redundancy but high FAR data, centralized tracking outperforms distributed tracking. The centralized tracker maintains track more effectively due to a higher input data rate as compared with single-sensor trackers in the distributed architecture. The high data rate leads to smaller data association gates, which is crucial in high FAR environments.
- In high FAR environments with low detection redundancy, both centralized and distributed tracking architectures are severely challenged. A possibility for addressing this performance shortfall is to develop a hybrid track management scheme that leverages the performance advantages of both centralized and distributed architectures. This approach builds on the research presented in [4].

2 SENSOR MANAGEMENT

Sensor management functions impact the data acquisition and signal and information processing functions that precede the target tracking and data fusion component of the surveillance processing chain. Sensor management provides a closed loop that takes the current consolidated surveillance picture and redirects the acquisition and processing functions. We categorize sensor management functions as follows:

- *Outer loop*: transmission scheduling, waveform selection, asset path planning, etc. These functions impact the raw data acquisition.
- *Inner loop*: adaptive data thresholding, etc. These functions impact the formation of contacts generated by signal and information processing, without impacting the raw data acquisition.

Outer loop sensor management functions for multistatic sonar are the subject of a number of research efforts including [5-6]. Inner loop sensor management is logistically much simpler as it does not require interaction with sensor assets. Our particular interest is in adaptive thresholding of contact data, by which we mean the use of a lower SNR detection threshold in the vicinity of confirmed active sonar tracks. This technology has been studied in [7] in the context of a probabilistic approach to data association and tracking for radar tracking. The finding was that it is advantageous to employ this technique, much as a trained operator does heuristically by focusing attention on areas of interest in a detection display.

We have not yet tested use of adaptive thresholding in closed-loop processing of active sonar contact files. In the following section, we apply adaptive thresholding to our tracker performance model as a means of identifying the potential of integrated detection and tracking for improved active sonar-based undersea surveillance.

3 INTEGRATED DETECTION AND TRACKING: ADAPTIVE THRESHOLDING

The tracker performance model developed in [3] provides a means for quantifying expected tracker performance in a *tracker operating characteristics* (TOC) curve sense, which maps track detection probability vs. false track rate as a function of track initiation parameters. The TOC curve can be directly compared against the input ROC curve that describes the detection quality of the input contact data.

The TOC curve depends on the input ROC curve as well as key scenarios assumptions and tracker parameters, including the size of the surveillance region, target kinematic and detectability assumptions, contact localization errors, and tracker parameters including the size of the data association gate and track termination criterion. By varying track initiation parameters in the *M-of-N* logic-based track initiation scheme, the TOC curve results.

We use the same settings as in the first example in the case study documented in [3]:

- Number of sensors: 10;
- Surveillance area: $(10\text{km})^2$;
- Ping repetition time: 60sec;
- Average detection cell size: $(10\text{m})^2$;
- Low target SNR: 10dB;
- High target SNR: 15dB;
- Measurement error variance in x and y dimensions: 10m;
- Track termination: 3 missed detections;
- Track association gate: 99%;
- Target dynamics process noise in x and y dimensions: q=0.01m^2/sec^3;
- Transition rates for target SNR state: $\lambda = 0.1\,\text{sec}^{-1}$ (high);
- Detection threshold: DT=10dB.

The tracker M-of-N track initiation settings are varied over the following range, shown in Table 1.

Table 1: Track initiation parameter settings.

M	2	2	2	2	3	3	3	3	4	4	4	4	5	5
N	2	3	4	5	3	4	5	6	4	5	6	7	5	6

M	5	5	6	6	6	6	7	7	7	7	8	8	8	8
N	7	8	6	7	8	9	7	8	9	10	8	9	10	11

The detection threshold of 10dB noted above is the global detection threshold. In addition, we introduce a local detection threshold that applies in the vicinity of confirmed active sonar tracks. We consider three choices for the local detection threshold: 10dB, 9dB, and 8dB.

TOC curves resulting from the three choices of local detection thresholds for the single-sensor, multi-sensor centralized, and multi-sensor distributed trackers, are shown in Figure 1.

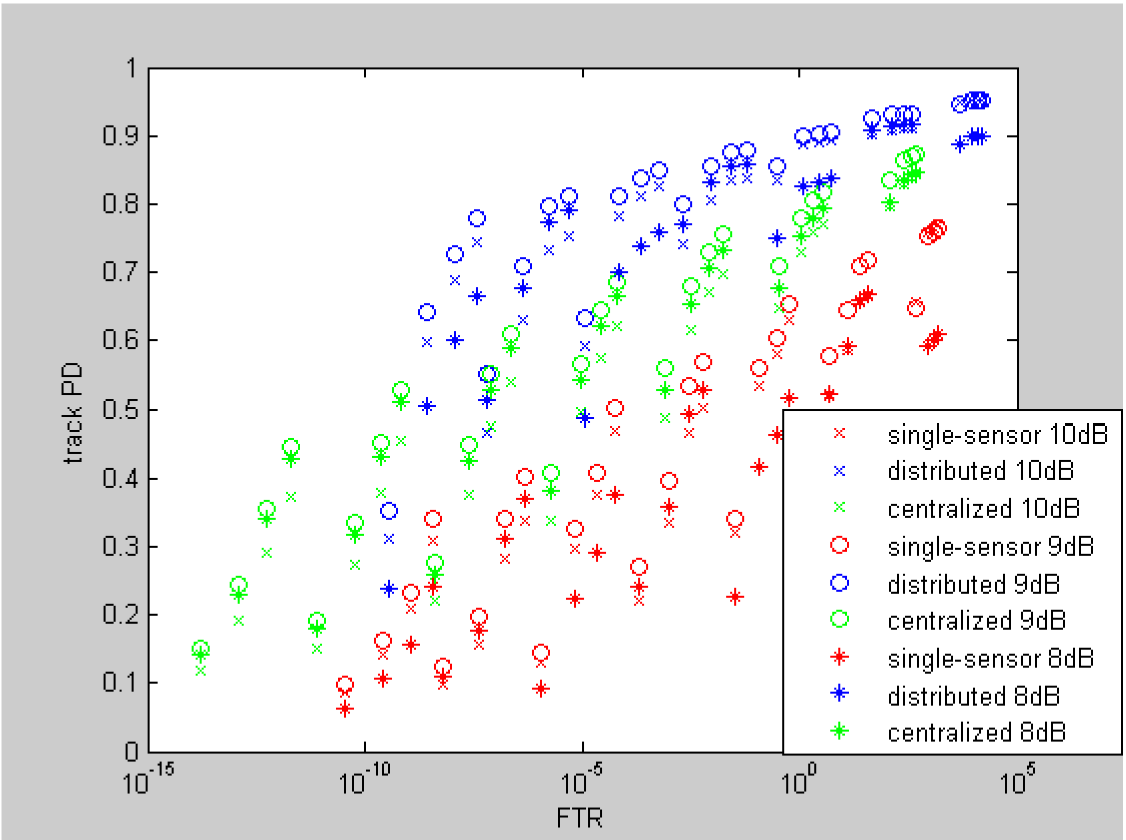

Figure 1: TOC curves for various choices of tracker architecture and local SNR detection threshold.

From these results, we see the following:

- A modest reduction in detection threshold for local detection in the vicinity of confirmed active tracks provides improved track maintenance performance due to an increased detection probability, with only a minor detrimental impact due to additional false contacts in the association gate;
- A more substantial reduction in detection threshold leads to an unacceptably high number of false contacts in the association gate, leading to an overall reduction in track maintenance performance.

The choice of local threshold does not impact the track initiation time. Thus, the impact on track maintenance performance directly impacts the track detection probability, which is defined as the average track maintenance time divided by the sum of average track maintenance time and average track initiation time.

Furthermore, the local detection threshold only trivially impacts the false track rate, and indeed this impact is not even modelled in our tracker performance modelling work.

Thus, we conclude that modest reductions in local detection threshold (on the order of 1dB) provide a small but non-trivial tracker performance benefit in a TOC curve sense. More marked reductions lead to significant undesirable effects that negate these performance benefits.

These finds are the same for single-sensor, centralized, and distributed fusion architectures.

4 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Adaptive thresholding provides a straightforward mechanism for inner loop sensor management that does not impact data acquisition functions, and provides a performance benefit in terms of the quality of the consolidated surveillance picture. Outer loop sensor management requires a more complex surveillance and sensor management infrastructure as it requires interaction between the surveillance system and the scheduling of sensor acquisition functions.

Future work will include validation of our model-based adaptive thresholding results with actual tracker processing on simulated and sea trial based contact data. Additionally, we plan to address outer loop sensor management for multistatic sonar to include ping scheduling, waveform selection, and asset path planning. Finally, our research will include further enhancement of the DMHT tracker [2] to include Doppler-aided, classification-aided, and feature-aided functionality.

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