Narrowband Passive Sonar Tracking

Kevin Brinkmann and Jörg Hurka

ATLAS ELEKTRONIK GmbH, Sebaldsbrücker Heerstr. 235, 28309 Bremen

Email: {kevin.brinkmann, joerg.hurka}@atlas-elektronik.com

Abstract: Passive sonar sensors are the main source of information for a submerged submarine. Modern sonar systems like ISUS 90 offer a number of acoustic antennas and combined signal processing for broadband and narrowband detection and analysis of target noise. While broadband detection is often used to obtain an overview of the targets surrounding the own ship, narrowband processing enables the detection of target characteristic frequency lines, often produced by vibrations of the propulsion systems on surface ships which are radiated into the water. Narrowband processing is therefore essential for target analysis and classification. Frequency line information can be used to separate targets closely spaced in bearing, e.g. during target crossing situations, which can not be resolved by the broadband passive sonar information alone. In addition, target bearing histories containing frequency line information may be used in the Target Motion Analysis module to infer about target course, speed and range without an own-boat manoeuvre. Therefore, narrowband passive sonar tracking provides an additional valuable source of information and enhances the capabilities of a submarine sonar and combat system. In this paper we present multi-target tracking results for narrowband passive sonar based on a multi-hypothesis tracking approach. The tracking system is designed to automatically track all detectable frequency lines of multiple targets, while at the same time minimizing the number of false tracks.

1   Introduction

Surface ships and other naval platforms radiate broadband and narrowband noise originating from their propulsion system and other machinery into the water. A submerged submarine entirely relies on these acoustic signals for long range detection and surveillance. Because the use of active sonar leads to an increased counter detection probability, submariners usually rely on passive sonar. A typical ATLAS ELEKTRONIK ISUS 90 sonar suite for a modern conventional U 214 class submarine offers three important antenna systems for analyzing the incoming acoustic waves. The Cylindrical Hydrophone Array (CHA), located in the bow of the submarine, the Flank Array (FA) which is located at both sides of the submarine, and the Towed Array (TA), a flexible line array which can be deployed from a winch system in the rear part of the submarine. For the CHA, the FA, and the TA there are in parallel broadband and narrowband signal processing chains. While the narrowband processing is essential for target analysis and classification, broadband detection gives an overview of the targets surrounding the own ship. Apart from the Passive Ranging Sonar (PRS) not considered in the present contribution, passive sonar only provides bearing information. In order to derive target range estimates, bearing tracks of the detected targets of interest are formed. These target bearing histories are input to

the Target Motion Analysis (TMA) module which estimates course, speed and range of the target under consideration. In this way, a tactical picture of the sea area of operation can be compiled. In order to reduce the errors in the TMA solution, high quality bearing tracks entering the TMA algorithm are essential. Information like frequency lines, accessible by analyzing the narrowband processing output, ascribed to a particular bearing track could serve useful additional parameters to enhance the performance of the TMA module, namely it enables the system to derive target range estimates without the necessity of an own boat manoeuvre.

In current operational sonar systems, the initialization, maintenance, and deletion of target bearing tracks as well as tracks formed from the detected frequency lines is typically performed by the operator.

The paper in which we present a novel multi-target tracking algorithm for narrowband passive sonar based on a multi-hypothesis tracking approach is organized as follows. Section 2 reviews some of the narrowband passive sonar specific features which are of interest in the tracking context. In Section 3 we briefly describe our multi-target tracking system and the algorithms used within it. Narrowband passive sonar tracking results for the Flank Array are presented in Section 4. In Section 5, we summarize and draw conclusions.

2   Narrowband Passive Sonar

Narrowband passive sonar aims at the detection of characteristic frequency lines emitted by a target vessel. There are two related but different origins for such frequency lines: i) the propulsion systems on board a naval ship and ii) the physical effect of cavitation. Depending on the origin, it has to be distinguished between tonals, i.e. discrete frequency lines transmitted directly in the water column, and indirect frequency lines. The latter can only be detected by the application of an algorithm which searches for characteristic modulations of the broadband noise emitted by the ship.

The propulsion system of a ship, for example a diesel engine, produces cyclic repetitions of moveable machinery parts due to the operation of the cylinders. For proper functioning, the engine additionally needs a number of ancillary units and several pumps (transport of lubricants or oil). The work of the engine due to its strong coupling to the hull of the ship therefore results in vibrations of various frequencies which are transported into the water. Information on typical frequencies which can be resolved and identified by narrowband passive sonar are the cylinder firing rate, the engine firing rate (cylinder firing rate times number of cylinders) and the crank shaft rate. These frequency lines are typically found in the low frequency range.

Cavitation is the effect of gas bubble formation close to the tips and on the faces of the propeller blades of a ship. The pressure of the moving water in the layer close to the blade is severely lowered, thus allowing vaporization. The bubbles have a characteristic average life time after which they collapse. The bubble implosions can cause severe damages to the propeller blades and additionally are the source of noise generated by the propeller. The generated noise has characteristic modulation frequencies which contain information

about the number of blades and the turning rate of the propeller (propeller shaft rate).

The quantity of interest in narrowband passive sonar is the spectral content of the incoming sound from all directions, integrated over a certain interval of time. Due to the application of a beamforming operation, the incoming sound is easily separable into its directional origins. Two modes of operation can be used to analyze the sound, namely the LOFAR signal processing which is sensitive for direct frequency lines and the DEMON signal processing which has the capability to detect the indirect frequency lines. The acronym LOFAR stands for **LO**w **F**requency **A**nalysis and **R**ecording, DEMON stands for **D**etection of **E**nvelope **MO**dulation on **N**oise.

3 Multiple-Hypothesis Approach

Modern tracking systems are very often designed as multi-target tracking (MTT) systems allowing the simultaneous tracking of a great number of physical objects (a detailed introduction can be found in Ref. [BP99]). An integral part of any such system is a physical sensor, e.g., a radar or a sonar sensor. In the MTT case the sensor typically has a large field of view (FOV) which is scanned in order to process all objects in this region at a time. The sensor signal processing periodically generates lists of detections, e.g., detected radar echoes in the case of active radar, which are passed on to the tracking unit. The task of the tracking unit is the logical combination of recurring sensor detections which emerged from one particular object and the estimation of its kinematical parameters. Due to the fact that the list of detections per scan not only contains measurements from objects of interest but also false alarms this becomes a sophisticated challenge.

Under realistic conditions, the tracking system has to deal with a number of uncertainties like erroneous measurements, limited sensor resolution, imprecise knowledge of the object motion and high false alarm rates. In our proposed approach the tracking unit is composed of three interrelated main elements. One is responsible for state estimation, the other two for data association and management tasks respectively (cf. Ref. [BH09]). The state estimation block in combination with the data association block forms tentative tracks, tentative, because the tracking system will treat them as candidates for real tracks. The data association uses the multi-hypotheses approach, where multiple new detections are assigned to a particular given track and a hypothesis tree is processed in order to consider more than one data interpretation history [BP99, Koc01, BH09].

The management block has to cope with tasks like track extraction, track deletion and track maintenance. In the particular case of narrowband passive sonar as discussed in this contribution, the probability is high that a target emits more than one specific frequency. The management block has the capabilities to extract all of these lines. The tracks formed by the MHT, the multi line tracks (MLT's) hold information about all frequencies emitted by one particular target, thus, for each considered time interval it is characterized by a bearing value and one or more frequency values.
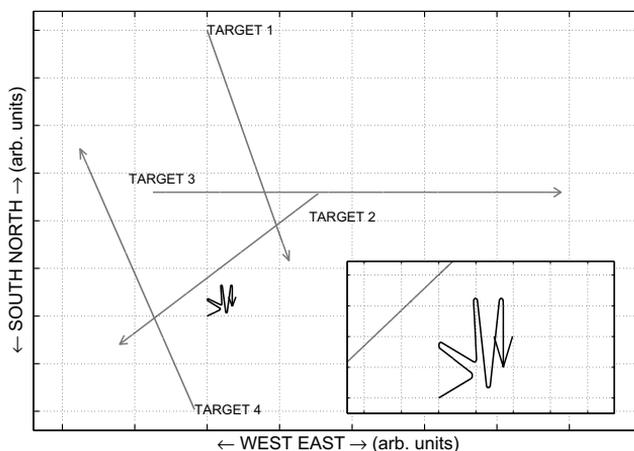
Figure 1: Geometry of the simulated scenario.

4 Simulation Example

In this section we present results of our multi-target tracking algorithm applied on a simulated scenario with a duration of 80 minutes. The scenario contains four different surface vessels traveling with constant course and speed. During the time of the scenario the own submarine performs typical TMA manoeuvres. The target trajectories are shown as red lines in Fig. 1. The inset magnifies the own submarines trajectory. The following frequency lines are given: Target 1: 400 Hz, 450 Hz, 520 Hz, 570 Hz, Target 2: 580 Hz, 620 Hz, 690 Hz, 715 Hz, Target 3: 430 Hz, 525 Hz, 685 Hz, 1000 Hz and Target 4: 867 Hz, 879 Hz, 900 Hz, 917 Hz.

The acoustic information, generated during the simulation, is fed into the sonar signal processing units responsible for extracting direct frequency lines, i.e., the LOFAR processing chain. The detection algorithm extracts possible target frequency line detections.

The list of detections for each time step is subsequently fed into the narrowband passive sonar version of the MHT which performs the estimation and data association steps described in Sec. 3. If a collection of recurring frequency line detections passes the confirmation test, a tentative MLT becomes extracted after a particular amount of time. Deletion of a MLT is initiated if it becomes very unlikely to originate from a true target.

Figure 2 presents the tracking results obtained for the FAS-LOFAR data. In this case the results showing the bearings of the extracted MLT's. These are drawn as blue lines with the respective track number displayed at the beginning of each MLT. The green dots represent bearings of the frequency lines extracted by the detection algorithm. The own course is drawn in black. Each detection occurring in the blind zone of the acoustic sensor is highlighted in magenta. It can be seen that all the MLT's formed by the narrowband version of the MHT originate from one of the four vessels present in the simulated scenario. As
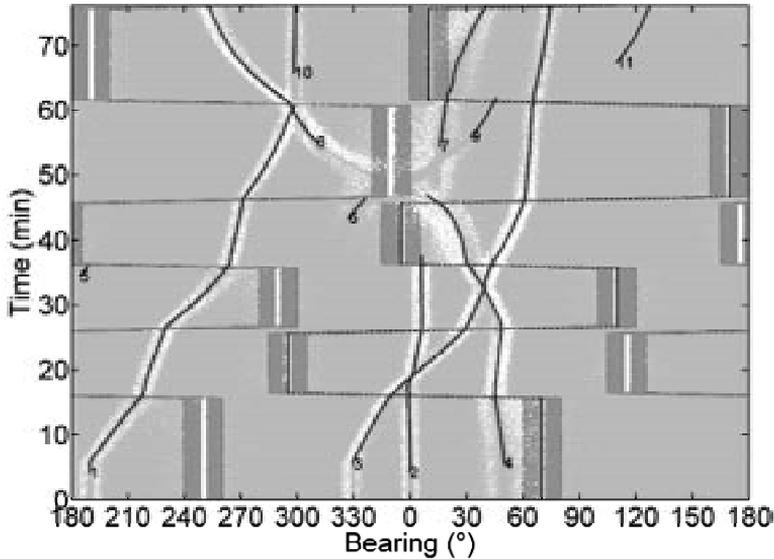
Figure 2: Tracking results showing the bearing of extracted MLT's.

it was the case for the broadband passive sonar results [BH09], the trajectory for one particular target usually consists of several extracted MLT's. However, notice that for the narrowband processing a break in the extracted tracks does not necessarily occur during target crossing situations but mainly due to the imperfections of the sensor. For example, the trajectory of target 4 is composed of MLT's no. 1 and no. 10. The trajectory for target 1 is composed of the MLT's no. 2 and no. 7 and the one for target 2 of MLT's no. 4 and no. 8 respectively. The trajectory of target 3 is build up by just one extracted MLT (no. 3). Being a linear array, the Flank Array in direct frequency line detection mode also leads to the extraction of mirror targets, i.e., the MLT's no. 5, no. 6, no. 9 and no. 11, all of which are mirrors from the target trajectory of vessel 2.

Figure 3 shows the tracking results for the FAS-LOFAR data, especially the frequencies of the extracted MLT's. The frequency lines with the respective numbers of the MLT to which they belong to are shown as blue lines. Because a particular MLT contains more than one frequency line, in this figure specific track numbers occur more than once. The mirror targets (MLT's no. 5, no. 6, no. 9 and no. 11) are clearly observable due to the fact that they perfectly overlay on the frequency lines of MLT no. 4 and no. 8. The profit of having more than one frequency line extracted by the MHT can be seen, for example, by inspection of the frequency lines around 900 Hz belonging to the MLT no. 1 in Fig. 3. At around 30 min the two lines with the higher frequencies are deleted by the MHT. The subsequently confirmed frequency lines (originating from the same vessel as the deleted ones) are correctly add to MLT no. 1, because the lower lines (867 Hz and 879 Hz) are still tracked by the MHT.
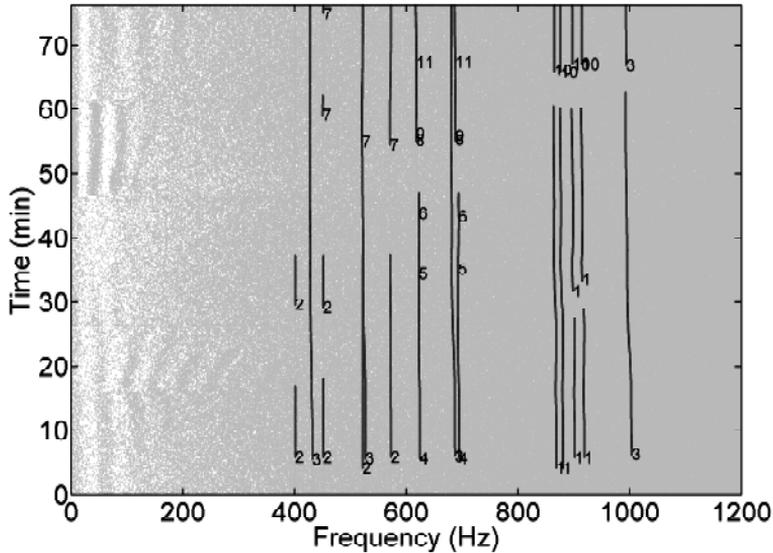
Figure 3: Tracking results showing the frequencies of extracted MLT's.

5 Summary and Conclusion

This paper introduced a multi-target tracking approach for narrowband passive sonar targets. After a review of some sonar specific features and a brief algorithm description, an application of this algorithm on the results of a simulated scenario was presented.

It was shown that this algorithm has the capability to automatically track the relevant frequency lines of all targets without a manual input by the user. It therefore has a great potential for a future tracking system.

References

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