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Defining and exploiting negative information for underwater surveillance

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Abstract

This Reference Document is an outline of a proposed research activity that will support multiple projects: 01dc (Maritime Information eXploitation), 01cg (CRACCEN), and 01ca (Force Anti-Submarine Warfare). It summarized initial thoughts with respect to the use of negative information as a contributor to underwater tracking and situational awareness in the information domain.

Résumé

Le présent document expose les grandes lignes d'une éventuelle activité de recherche qui viendra appuyer de nombreux projets: 01dc (Exploitation de l'information maritime), 01cg (CRACCEN) et 01ca (Force de lutte anti-sous-marine). Il résume les premières impressions sur l'utilisation de l'information négative pour faciliter la poursuite sous-marine et la connaissance de la situation dans le domaine de l'information.

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1 Introduction

Negative information (or negative evidence) is the absence of expected information [1, 2]. For example, if there is an expectation that an object could be found in a certain location, then it is not found there, its absence is negative information within the context of searching for that object. Making an inference from expected but missing information to gain insight is how negative information is exploited [2]. For example, an object that was not found in one of several likely locations, allows you to infer that the object is in one of the other locations.

This document is an outline of a single research activity, related to negative information, that will support multiple projects: 01dc (Maritime Information eXploitation), 01cg (CRACCEN), and 01ca (Force Anti-Submarine Warfare). Defining the negative information needed to support underwater surveillance will fall under project 01dc, algorithm development will fall under project 01cg, and acquiring knowledge of the sensor and sensor setup to better model the real world application will fall under project 01ca.

Research questions include: Can negative information be defined and used to:

- improve an acoustic target tracker's performance?
- track a target for a longer period of time in a degraded sensor environment?
- reduce the number of sensors required over an underwater area (i.e., increase sensor separation), while still allowing sufficient target tracking?

The research will use data obtained from the Distributed Underwater Sensor Nodes (DUSN) trial in Sweden in 2018.

Under project 01da, a literature review on the topic of negative information was conducted [3]. The following is an outline of a research plan for applying the concept of negative information explored in [3] to an underwater setting. For a single passive acoustic sensor, if there is an expectation that there is an object to be detected by a single sensor, the lack of detection above the detection threshold is negative information. The negative information could provide insight about an object, such as its position or its heading. The same can be said for a passive acoustic array for which not all (or any) sensors have detected the object.

The use of negative information has been shown to improve the tracking of objects. For example, negative information improved tracking results for objects that had moved into an area where the sensor was being jammed [4], for objects that were exploiting the limitations of a sensor [5], and for objects that had become occluded [6]. Reference [3] has further examples of exploiting negative information for tracking purposes. There has also been some work done in the Anti-Submarine Warfare (ASW) area, for example [7, 8].

Optimal underwater sensor placement has also been investigated in ocean acoustics research. For example, where to place sensors to best passively detect a diver through the sound of their breathing [9], as well as looking for the optimal underwater sensor network design when acoustic waves are used for both detection and communication [10], have been researched.

This work will define negative information in a manner sufficient to store the negative information (01dc) and exploit it within ASW (01cg, 01ca) in order to look at the benefits of adding it into an existing ASW tracker. The aim of the research is to determine if the benefits are sufficient to allow a reduction in the number of sensors needed in an acoustic array, while maintaining a suitable level of performance. A preliminary example of related work has been found for forward scatter tripwire arrays. Widdis [7] looked at optimal tripwire arrangement after improving their tracking algorithm by incorporating negative information. For their modelled environment, they looked into minimizing financial cost of the tripwire arrangement while maximizing localization of the target, while using their improved tracking algorithm.

2 Research plan

2.1 Summary research plan

The following outlines the steps of the research plan. In the next subsection, the steps are expanded upon by including further details and thoughts.

1. Add the use of negative information into the tracker.

2. Model the sensor performance.

3. Using data from a target transiting through the sensor area, determine the effectiveness of the tracker, with and without negative information being used, and validate with the ground truth.

4. Systematically remove "sensors" from the data set and assess how well the negative information tracker does without the benefit of data from those sensors. This introduces controlled negative information into the research.

5. Once convinced that negative information is improving the results, do an optimization analysis, using a similar environment and sensor model, as well as synthetic data, to determine optimal sensor placement for a tracker that incorporates negative information. The performance will be compared to a tracker that does not incorporate negative information.

2.2 Detailed research plan

The following expands on the research plan above, with author notes.

1. Add the use of negative information into the tracker.
   - ***Section 2*** of the author's "Negative Information Literature Review" [3] should be very applicable as background to do this.
   - Some of the papers listed in ***Annex A*** of [3] (reports that were not reviewed) will be looked at, as several are adding in negative information into trackers meant to be used in an ASW setting.
   - The existence of classified papers will be investigated with the help of the Defence Research and Development Canada (DRDC) library.

2. Model the sensor performance.
   - See Section 3 regarding the data needed to build the sensor model.

3. Using data from a target transiting through the sensor area, determine the effectiveness of the tracker, with and without negative information being used, and validate with the ground truth. (*See* Figure 1.)
   - There will be naturally occurring negative information if there are times when no sensor is picking up the target while it is travelling through the area.

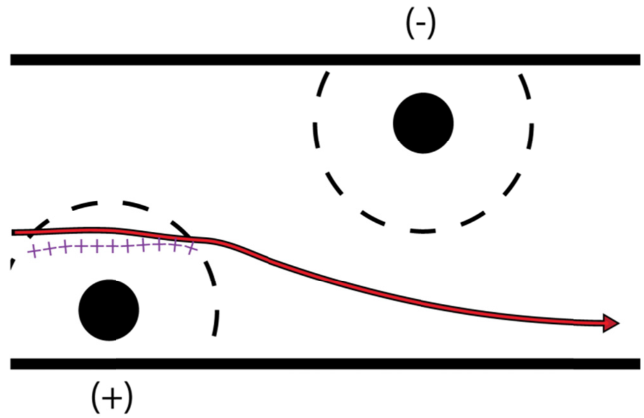

Figure 1: *Target travelling through sensor area. Red line is ground truth, target moving left to right. Purple pluses are positive information. (The mismatch is intentional.) Dashed line is extent of sensor coverage. "Naturally occurring negative information" occurs because the target is not detected by one of the sensors.*

4. Systematically remove "sensors" from the data set and assess how well the negative information tracker does without the benefit of data from those sensors. (see Figure 2.) This introduces controlled negative information into the research.

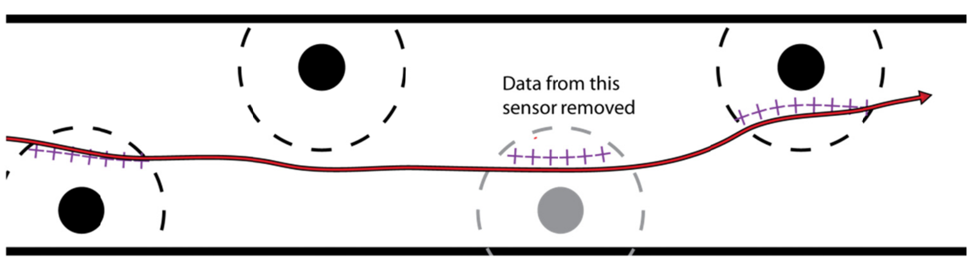

Figure 2: *Target travelling through sensor area. Some collected data has been removed. Red line is ground truth, target moving left to right. Purple pluses are positive information. Greyed out sensor represents a sensor that produced positive information but its data were removed to test the tracker.*

5. Once convinced that negative information is improving the results, do an optimization analysis, using a similar environment and sensor model, as well as synthetic data, to determine optimal sensor placement for a tracker that incorporates negative information. The performance will be compared to a tracker that does not incorporate negative information.

- Measures of effectiveness will be needed to assess negative information's impact on the tracking algorithm. Some of the Naval Postgraduate School theses that were in ***Annex A*** of [3] may be useful in this regard.
- Techniques on optimizing underwater sensor positions will be reviewed. Initial papers by Blounin [10], Stolkin [9, 11] and Widdis [7] have already been reviewed.
  - The Stolkin papers [9, 11] are of particular interest where the authors defined a "swimmer number" which was the integration of the spectrogram of the hydrophone signal envelope

for the feature corresponding to a swimmer breathing. Essentially, they were able to optimize the number of sensors and the positions of the sensors. Given the probability approach taken by the authors, there might be some aspects applicable to ASW.

- Once the optimization problem is better understood, an algorithm developed previously [12] might be suitable for application to this problem. The technique is for complex optimization.

3 Experimental requirements

The following are required from the DUSN trial:

- The tracker.
  - Source code will be required so that a computer scientist can modify the code.
- Ground truth of the target.
  - E.g., GPS
- Ground truth positions of the sensors, as deployed.
  - E.g., GPS
- Data needed to build a sensor model.
  - The goal is to be able to build a realistic sensor model with the data collected, for this environment and for this trial.
  - Figure 3 gives an example of how to build a sensor model using real data: transit a sensor, at 45 degree intervals (i.e., 4 transits, see Figure 3), to get a sense of where the sensor picks up / drops the target. Ideally this would be done for each sensor.

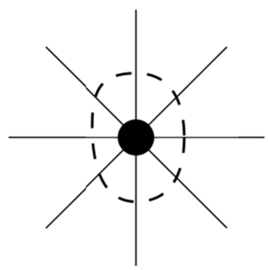

Figure 3: *Building a sensor model using collected data. Circle represents sensor. Dashed line represents sensing extent. Straight lines represent transits over sensor.*

  - It is possible that knowledge of the power of the target detection will be useful because the target strength is likely proportional to the probability of being detected, where higher power implies higher probability.
  - Alternatively or in addition to a sensor model built like in Figure 3, a sensor model can be built mathematically. For example through the use of an appropriate acoustic propagation model with known parameters as inputs. A sufficiently accurate model would be required such that the results are comparable to reality.
- Sensor data to be used by the modified tracker to track the target.
  - Transit the experimental area to create multiple tracks to use to assess the tracker.
    - **Simple paths** will be best (e.g., no tight figure 8s)
    - The target maintaining a **constant speed** would help rule out that complication during analysis.

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