DEFICIENCIES IN AUV MISSION PLANNING EXEMPLIFIED BY AN UXO SURVEY

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Abstract: *At the end of WW II hundreds of thousands of tons of unused ammunition and explosive ordnances were just skipped over the railing of some fishing boats to get rid of them.*
Out of sight, out of mind was the motto, and nobody cared about the consequences. That was daily practice up to the late sixties. All together there are about 1.6 million tons of UXOs in German littoral waters.
In recent years the AUV team of the WTD 71 supported the Waterways and Shipping Directorate in searching UXOs in littoral waters. The variety of UXO reaches from boxes with ammunition for assault rifles up to torpedoes and cruise missiles of type V-1.

During these AUV surveys it turned out, that due to the environment, the sonar performance varied a lot over space and time and this lead to gaps in the coverage of the surveyed area.
But, modern Synthetic Aperture Sonars (SAS) offer the capability to overcome these deficiencies by estimating the actual usable sonar range. If the image quality decreases, the line spacing between two consecutive tracks will be adapted to shorter distances autonomously. With this technique the coverage of the area is always up to 100%.

Keywords: *AUV, UXO, Mission Planning, Adaptive Linespacing*

1. Introduction

At the end of WW II hundreds of thousands of tons of unused ammunition and explosive ordnances were just skipped over the railing of some fishing boats to get rid of them.

Out of sight, out of mind was the motto and nobody cared about the consequences. That was daily practice up to the late sixties. All together there are about 1.6 million tons of unexploded ordnances (UXO) and discarded military munitions (DMM) in German littoral waters and not all of them are non-ignited.

Figure: 1 Boxes with ammunition were dropped not far from the coast

The authorities are concerned that both chemical and conventional munition present in the marine environment poses a threat to the health and safety of humans as well as marine life. And through corrosion and chemical changes these devices might become more volatile, thus increasing the danger of unexpected explosions.

Since the bomb shells are suffering under the seawater conditions and more and more of them just corroded away, the number of incidents with exposed explosive or phosphorus lying on the beach is increasing. In Germany not the Navy is in charge of UXO disposal but the Waterways and Shipping Directorate. In recent years the AUV team of WTD 71 supported the Waterways and Shipping Directorate in searching UXOs in littoral waters. The variety of UXO reaches from boxes with ammunition for assault rifles up to torpedoes and cruise missiles of type V-1.

During these AUV surveys it turned out, that due to the environment, the sonar performance varies a lot over space and time and this lead to gaps in the coverage of the surveyed area.

But modern SAS sonars offer the capability to overcome these deficiencies by estimating the actual sonar. If the image quality decreases, the distance between two consecutive tracks will be adapted autonomously. With this technique the coverage of the area is always up to 100%.

2. Deficiencies

Before the new method of mission planning is presented, it is necessary to clarify how the conventional method works and where the difficulties lie.

The planning of an AUV mission usually starts with the assignment of an area to be investigated. The task of the operator is now to plan a mission, which in the end provides a complete coverage of the area with a constantly high image quality. A high image quality is the first threshold for getting a high probability of detection.

The sonar performance has to be estimated under the given conditions, using known data, such as seabed complexity, water depth, stratification of water and other parameters. On the one hand, the operator relies on experiences from the past, on the other hand also on databases and possibly also on results of test dives. In such test runs, called "Sonar Condition Check", it must always be taken into account that this is usually done outside the actual search area and can only provide a local impression of the conditions. However, since the variability of these conditions can be very high such freshly acquired data has only of limited value and also cost valuable time.

In the end the operator settles down and plans the upcoming mission.

In summary he has to assess and consider the following parameters:

- water depth
- duration
- energy consumption
- height above ground
- driving depth
- currents
- sonar range
- stratification
- mine threats
- texture of the seabed (sediment type, clutter, etc.)
- roughness of the sea surface

Each of these parameters can be variable and the operator has to estimate what influence every single parameter has on the sonar performance and ultimately on the PC (Percentage Clearance).

This is a complex problem that has not even theoretically been solved and which also depends on some parameters that are not available a priori.

As explained before a large number of factors have to be taken into consideration when planning and conducting a successful mission using an AUV. The task of the AUV operator is therefore first of all to determine the altitude and the range of the sonar under the given boundary conditions.

With these values and the inclusion of the "fear factor" he plans the mission.

The typical search patterns with side-looking sonars basically have an alternating linespacing from leg to leg. This is due to the fact that a gap remains on the first leg underneath the vehicle (Nadir) where no usable sonar data is available. This is due to physics and does not depend on environmental factors. To close this gap, the second leg is placed in a way so that the gap of the first leg lies exactly in the well-covered area of the second one. So only a pair of legs gives a closed area. The distance of the third leg is almost twice the size of the estimated sonar range since only a small overlap between the outer regions of the covered range has to be taken into account. This is illustrated in figure 2

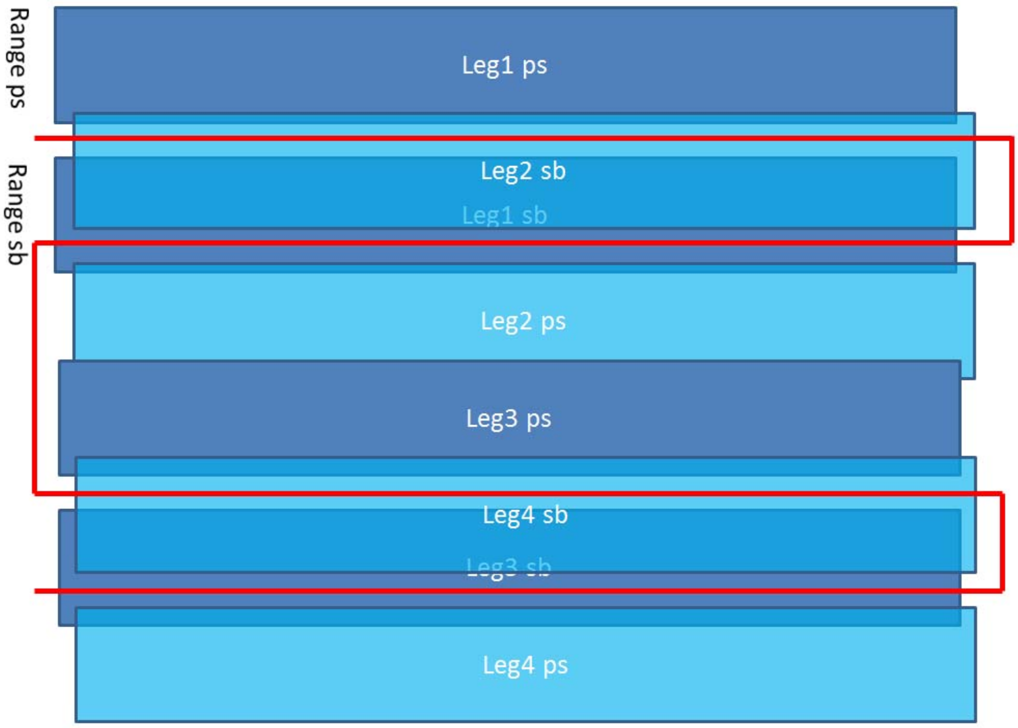

Figure: 2 Leg 1 to 4 (portside and starboard) of a typical asymmetric search pattern for side-looking sonars

A ratio of 25/75 has become established from the times of the conventional side-scan sonars. This means that at a maximum expected range of 100 m and a resulting swath width of 200 m, the offset in the first to the second leg is 25% of 200 m, which is 50 m and the offset from the second to the third leg is 75%, which is 150 m.

After launching the mission, the vehicle conducts the entire mission following the given search pattern with pre-programmed waypoints and payload settings.

After completion of the mission the data is processed and then evaluated by an operator. This will be the moment where he often recognizes the regions in which image-evaluation is not possible due to quality-fading factors such as multipath propagation. In conventional side scan sonar images only a well-trained operator is capable to distinguish between flat seafloor regions of high image quality and blurred regions of poor image quality. In the end, these gaps lead to another mission to close them. This is time consuming and not very effective.

Since the evaluation of images is not a reliable method to determine whether a region is of good image quality or not the new method is based on the evaluation of raw signal data. A precondition for this method is a sonar that provides an estimation of the distance-dependent sonar performance. This can be achieved by evaluating the complex data of either two consecutive pings or – in case of a bathymetric sonar – the phase evaluation of the two signals from the upper and lower receiver antenna.

By evaluation of the coherence between the two signals it is possible to determine the distance up to which the processing of the data provides presumably good image quality. This can be done with every single ping, so that in the end there is a vector of N values, indicating the maximum usable sonar range along a leg. The purple line in figure 3 gives an impression of this feature. This line is independent of the skills of an operator and is an objective criterion for the determination of what we call the usable sonar range (USR).

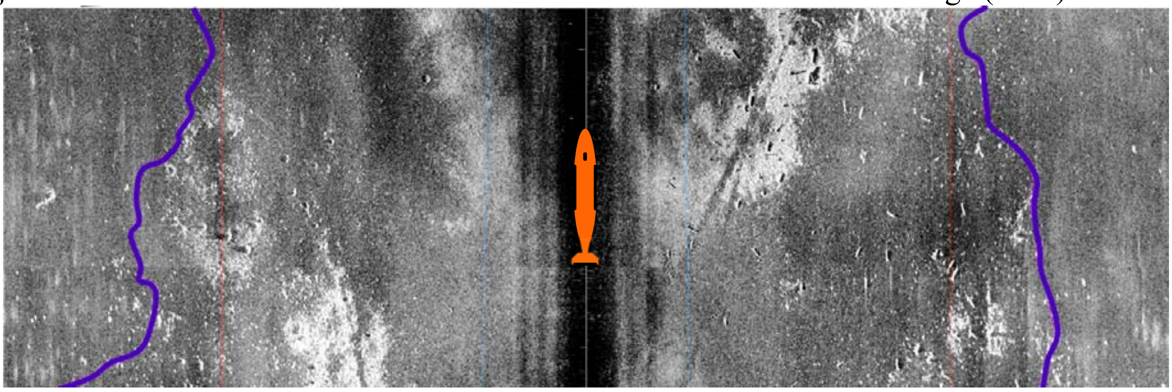

Figure: 3 The purple line is an indicator up to which range the data processing works well. This indicator does not depend on the content of the image and is available in real-time.

In figure 4 the results of a real mission are shown. The USR decreases in the easterly parts of the area and this leads to huge uncovered gaps where no evaluation of the sonar data is possible. The mission started in the north-western corner. The overlap between the legs at that site was more than sufficient. So the operator has done nothing wrong, but nevertheless he ended up in an incomplete survey.

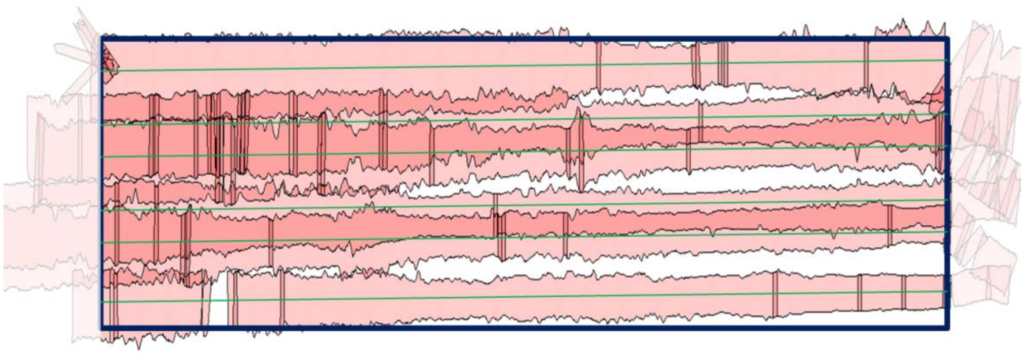

Figure: 4 Map of the covered area. Red areas indicate regions with evaluable regions. The darker the colour, the more often this region has been covered. White sections are uncovered gaps.

To overcome this problem the USR is used to determine an optimized linespacing in realtime. In the following chapter this new approach will be described.

3. Adaptive Linespacing

This chapter describes how to get the proper value for linespacing and which results can be achieved with this method.

3.1 Calculating the line spacing

The main characteristic of this approach is that the vehicle doesn’t stick to a pre-programmed mission plan. The operator only has to define the search area by a set of four coordinates, indicating the corners of the area. The first two coordinates will be used to determine a starting leg.
The easiest approach to find the spacing for the next leg would be to determine the shortest range of the USR over the length of the latest leg. But in case of dropouts with zero-values or singularities due to single objects this approach could lead to extremely short linespacing values and therefor to a very high leg density. In order to avoid such extreme sonar ranges we allow a certain percentage of the target area not to be covered. In the following paragraph we describe the instruction how to determine the proper linespacing value.

After finalization of a leg the algorithm takes all (N) values of the USR sampled along the leg and sort the stored range values in ascending order. After that we iterate over index i and determine the shortest range_i that fulfills the condition

$$\frac{\sum_{j=0}^{i}(\text{range}_i - \text{range}_j)}{(\text{range}_i - \text{range}_0) * N} * 100 \geq \ desired\ percentage$$

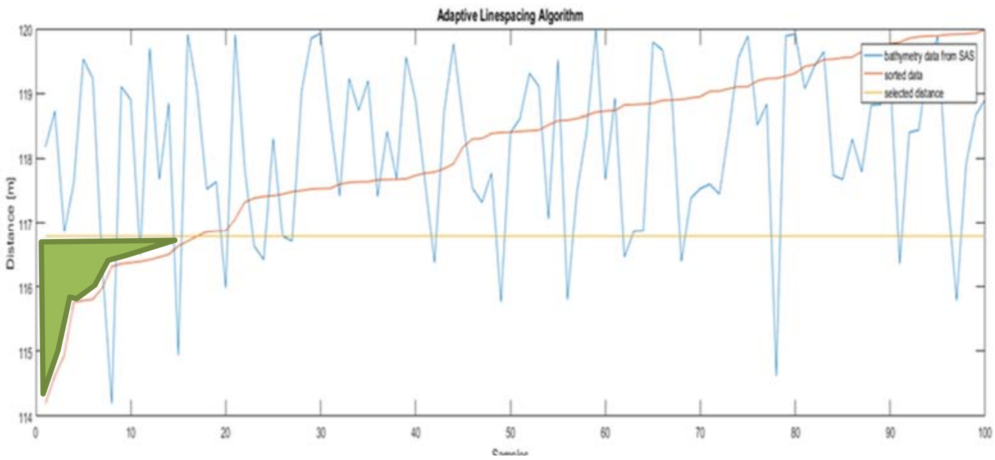

Figure: 5 The bathymetric data of the SAS (blue) shows some large fluctuations. Using the proposed algorithm on the sorted data (red) it outputs the selected distance (yellow).

In other words, we shift the yellow line from the bottom towards the top, looking for a point, where the ratio of the area left of the intersection between the red and the yellow line (green area) and the area underneath the yellow line is equal or bigger than a user defined threshold (usually between 5 to10%).

If the yellow line fulfills this criterion, the distance can be used for calculating the next leg.

4. Results

In figure 6 the difference between the conventional approach and the adaptive one can be seen. On the left side one can see the result of the conventional approach. The linespacing from leg to leg is constant. But due to a variable USR there are gaps in the coverage map. On the right hand side the linespacing is adapted to this variable USR and the area is fully covered. To reach this goal, the vehicle had to make an extra leg and the mission time was slightly longer than probably expected. But it wasn't necessary to go for another mission to fill the gaps.

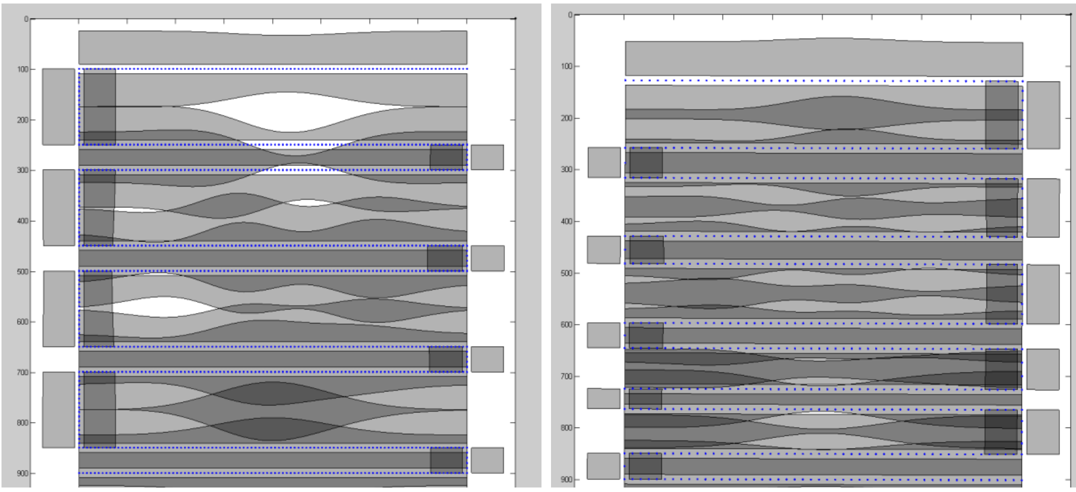

Figure: 6 On the left: A mission with preprogrammed waypoints, on the right a mission with adaptive linespacing. With the technique of adaptive linespacing a full coverage can be reliably achieved

5. Conclusions

By using the USR for optimization of the linespacing a much better coverage could be achieved. Currently the algorithm is optimized for cases in which the sonar range is worse than expected. In the future the system will also be adapted for the case that the USR is longer than expected. In this case the ping rate and the altitude will be adapted to longer ranges until the USR is smaller again than the given sonar range.
For the operator it might be unusual not to have an exact mission duration at the beginning of a mission, but the vehicle will be able to estimate the duration of the rest of a mission and send this estimation via a communication link to the operator.
The only case where this new approach might have some disadvantages is when you want to do detect mines by means of change detection. One precondition for this technique is that the vehicle runs more or less on the same tracks on different days. Due to the fact, that the environmental conditions can change rapidly, the vehicle will never run exactly the same mission twice and therefor the aspect angle will be different. This will make change detection much more challenging or even impossible.

It might also be possible to tweak the algorithm by taking the altitude more into consideration. Especially when there are boundary layers below the vehicle it might improve the output when flying at lower altitudes.
These sound speed profiles could be taken together with GPS updates.
In our opinion the adaptive linespacing is a technique that will be the standard for full coverage mappings in the future.

ACKNOWLEDGEMENTS

REFERENCE

ANNEXE