

About some Benefits of a Crossbearing TMA (XTMA)

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Abstract: A Bearing-Only TMA running on a submarine, which can exploit the crossbearing effect from sensors installed at different locations needs no own manoeuvre for convergence, if the parallax between the involved bearings exceeds a certain value. In this paper we discuss some results for the cases where data from a Towed Array is fused with data from an on-board sensor or the data of 2 on-board sensors are available. Finally, we describe a procedure for an automatic adjustment of the filter length of the non-recursive TMA filter by means of which it becomes even possible to handle targets which are not moving on a straight line.

1 Introduction

In the following we call a Bearing-Only TMA based on the crossbearing effect XTMA. We consider two different XTMA situations (s. Figure 1) with a Flank Array (FA) as one of the bearing sensors (s. [St01] and [St02]). The FA has its centre located at the conning

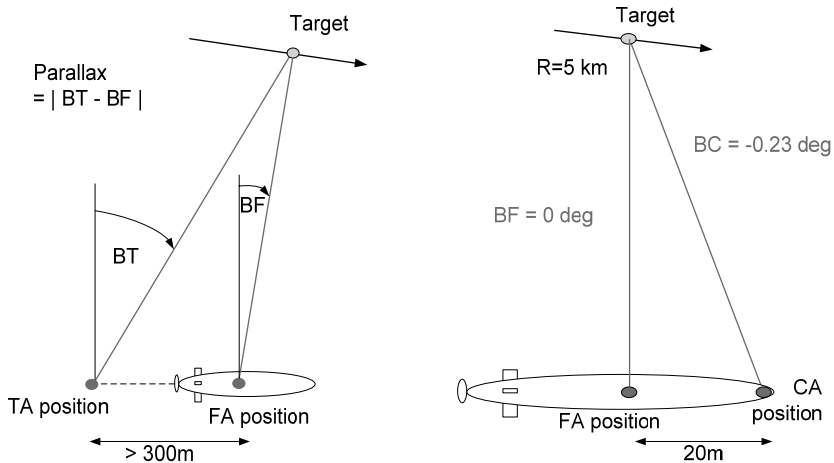


Figure 1: XTMA situations: FA with TA and FA with CA

tower. The second bearing sensor is either a Towed Array (TA) located at least 300m apart from the FA (depending on the launched tow length; left picture) or a Cylindrical Array (CA), which is located in the bow section of the submarine (right picture). The distance x between the installation locations of the FA and the CA sonar depends on the submarine type (e.g. $x=20\text{m}$ for 204 class; $x=30\text{m}$ for 209 class submarines). The XTMA estimates of the target parameters are expected to be the better the greater the parallax is. Figure 2 shows for a sensor distance of 30 and 300 m the resulting parallax as a function of the range of a target situated abeam to the own submarine.

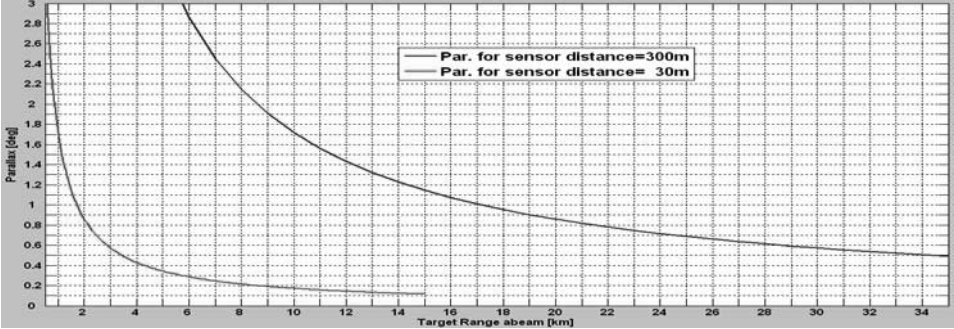


Figure 2: Parallax as function of target range abeam and sensor distance

2 XTMA with Towed Array and an on-board sensor (e.g. FA)

Considering the parallax, only, the FA/TA case is much superior to the FA/CA case, because the sensor distance and thus the parallax is at least 10 times greater. But the quality of the XTMA result is driven by the uncertainties of the input data, i.e. the bearings and the corresponding positions of the measuring array. These uncertainties are much higher in the FA/TA case. Typical values for the standard deviations of the bearings are 0.3 to 0.5 deg for CA, and FA, or 1.0 deg for the TA sensor.

To exploit the crossbearing effect it is essential to calculate for each array bearing the best possible corresponding sensor position (X_s, Y_s). For on-board sensors (X_s, Y_s) can be easily derived from the position (X, Y) of the inertial platform of the submarine (given e.g. by an integrated navigational system), the heading H of the own submarine, and the deltas (Sh, Sc) between the installation locations of the sensor and the platform in heading and cross heading direction of the submarine. These deltas are stored for each on-board sensor in a Sensor-Installation-Table (which is different for every submarine). For linear antennas this table contains 2 values for Sc , i.e. one for the starboard, and one for the port sensor. $X_s = X + Sh \cdot \sin H + Sc \cdot \cos H$; $Y_s = Y + Sh \cdot \cos H - Sc \cdot \sin H$. For a TA sensor the estimation of its position is much more complicated and can be done e.g. by means of a finite element algorithm, which needs as input data the position of the submarine, the launched tow-length, and information about the number and length of TA array elements, their diameters, CW-values, denses etc..

A lot of Monte Carlo simulations have shown, that the XTMA based on FA and TA bearings delivers usable results for targets approaching from an initial range up to 35 km (58 km), if the sensor distance is 300m (500m), or in other words for targets producing an initial parallax, which exceeds 0.5 deg.

3 XTMA with 2 on-board sensors (e.g. FA and CA)

Up to now a state of the art TMA based on bearings of on-board sensors, only, did not display any solution for range and speed to the operator as long as no own manoeuvre was performed. The XTMA based on CA and FA, however seems to be a tool to get rid of this disadvantage, although due to the small distance between the sensors useful results can be expected for close range targets, only. So we need a measure, which allows to detect the close range case such that the results are reliable and are worthwhile to be displayed to the operator. Simulations have shown, that a critical parallax P_0 , which must be exceeded, can be used as such a measure, where P_0 is defined as

$$P_0 = 1.8 * \sqrt{(\sigma(BC))^2 + (\sigma(BF))^2} / \sqrt{N_1 + N_2}, \text{ with}$$

$\sigma(BC)$, $\sigma(BF)$ = standard deviations of the CA, or FA bearings; N_1 , N_2 = number of CA, or FA bearings collected during a TMA-cycle (=20sec.). Assuming $\sigma(BC)=\sigma(BF)=0.5$ deg and $N_1=N_2=20$ results in a critical parallax $P_0=0.2$ deg.

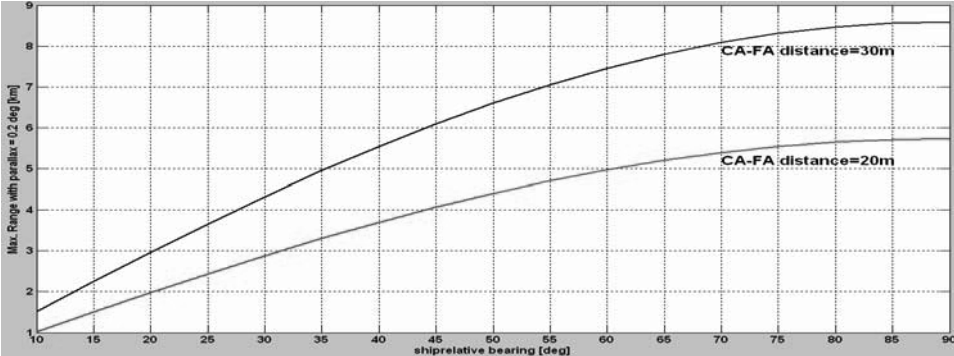
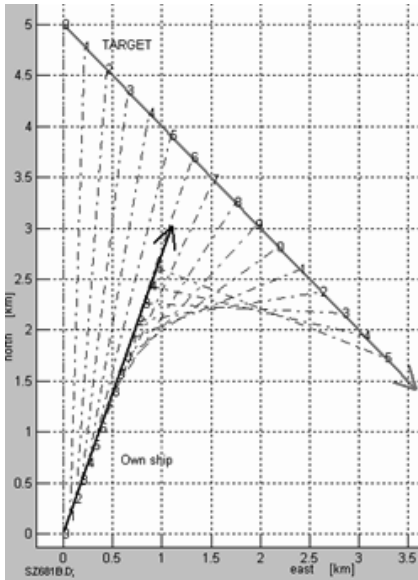


Figure 3: Max. Range for parallax=0.2 deg as a function of shiprelative bearing

Figure 3 shows, that the maximum range R_{max} , which just produces the critical parallax P_0 , decreases drastically, if the shiprelative bearing is away from the abeam direction.

During a dynamic scenario (see Figure 4), the target runs through different shiprelative bearings, such that the parallax between CA and FA bearings changes with time, and thus the value of R_{max} (= fictitious target) which guarantees at least the critical parallax P_0 changes with time, too.

A close range target check is therefore answered positive at time n , if the range estimate of the XTMA is less than R_{max} and the solution has settled. In this case all target parameters can be displayed to the operator even, if no own manoeuvre was performed.



The scenario displayed on the left shows a target, which produces at the beginning very small shiprelative bearings at the own ship. Therefore, at the beginning the resulting parallax is less than the required critical parallax P_0 (here = 0.2 deg). The lower plot shows, that P_0 can only be guaranteed by targets which fall inside the yellow area. The simulated target, however, enters this yellow area not before 8 minutes, such that the XTMA is expected to calculate useful results earliest after 8 min. This is confirmed by the overlaid run-in behaviour of the range estimate resulting from 20 Monte Carlo simulation runs for the XTMA. Simulated distance between CA and FA was 30 m; $\sigma(BC) = \sigma(BF) = 0.5$ deg.

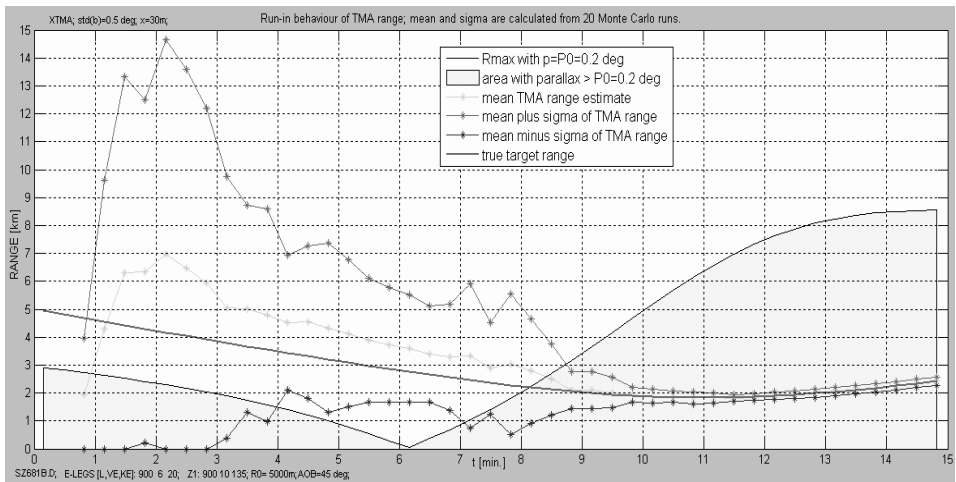


Figure 4: Example scenario for close range check

3 XTMA with dynamic filter length

A small filter length enables the XTMA to handle no-straight-line trajectories like target manoeuvres, or a torpedo approaching in bearing rider mode. But a fixed small filter length may disturb the solution, e.g. if the parallax becomes too small after an unfavourable own manoeuvre. Therefore, we derived by means of tedious simulation runs (different scenarios, different bearing sigmas, different constant filter length) a family of curves (s. Figure 5), which gives for different sigma combinations the

dependency between filter length and parallax to guarantee a range RMS-error of less than 8 %. Figure 6 demonstrates that the XTMA with dynamic filter length is able to follow a target manoeuvring in the vicinity of the own boat.

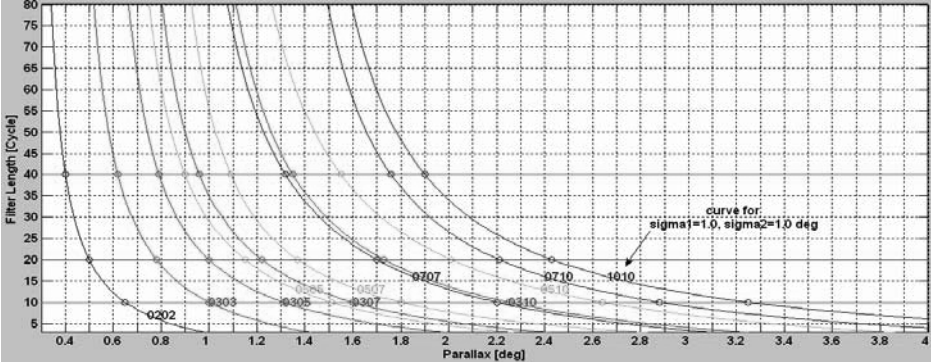


Figure 5: Family of curves; Filter length as function of parallax

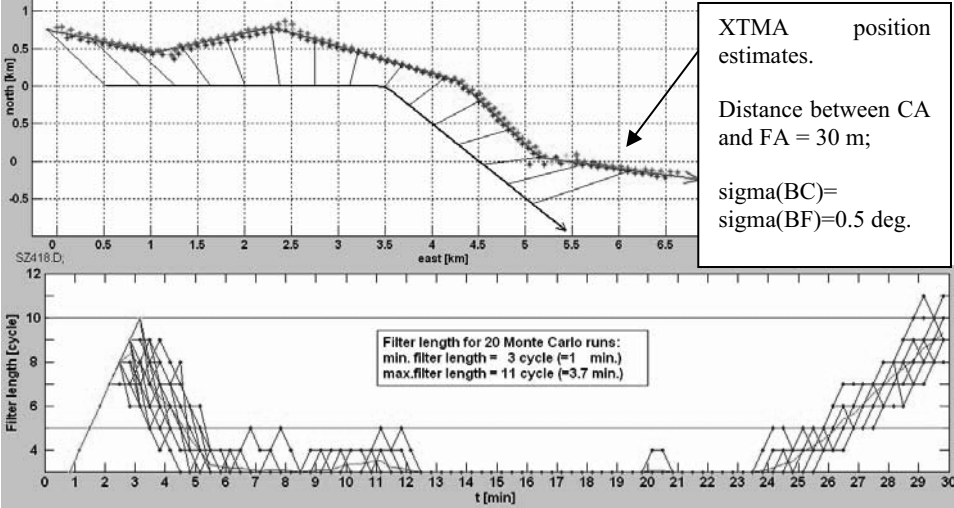


Figure 6: XTMA position estimates and corresponding dynamic filter length

References

[St01] Steimel, U: Some Advantages of Non-Recursive TMA Filters: conf. proc. of the NATO RTO SET-059 Symposium on 'Target Tracking and Sensor Data Fusion for Military Observation Systems', 15-17 Oct. 2003, Budapest, Hungary; 12 pages

[St02] Steimel, U: Some new Results on a Constraint TMA and a Close Range TMA; to be published in conference proceedings UDT Europe, Naples 5-7 June 2007; session paper 3D.2; 15 pages