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Statistical analysis of real radar target course and speed changes for the needs of multiple model tracking filter

Analiza statystyczna zmian kursów i prędkości obiektów śledzonych przez radar dla potrzeb wielomodelowej filtracji neuronowej

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Key words: statistical analysis, radar targets, course and speed changes, tracking filters

Abstract
The accuracy of calculating the parameters of another vessel movement and the consequent accuracy of determined ship encounter parameters is of key importance for collision avoidance and navigational safety. It is also essential to promptly detect a manoeuvre of another vessel, or target, especially where such manoeuvre cannot be detected by other methods, e.g. due to restricted visibility. Therefore, research in this field aims at improvement of radar target tracking methods.

Słowa kluczowe: analiza statystyczna, obiekty radarowe, zmiana kursu i prędkości, filtry śledzące

Abstrakt
Dokładność obliczenia parametrów ruchu obiektu obcego, a co za tym idzie, dokładność określenia parametrów spotkania statków ma kluczowe znaczenie z punktu widzenia unikania kolizji i bezpieczeństwa nawigacji. Istotna jest również szybkość wykrycia manewru obiektu obcego, zwłaszcza w sytuacji, gdy nie można tego manewru wykryć innymi metodami, np. z powodu ograniczonej widzialności. Prowadzone badania mają na celu udoskonalenie metod śledzenia obiektów radarowych.

Formulation of the problem

Radars with the automatic tracking function continue to be the basic collision avoidance system installed on sea-going ships. This results from the regulations in force and the fact that navigators got used to them. The International Maritime Organization (IMO) revised in 2000 the International Convention on Safety of Life at Sea (SOLAS) and introduced the AIS, Automatic Identification System. The system has to be carried by all passenger ships regardless of their capacity and on cargo ships with a capacity of 300 GRT and more, engaged in international trade, and on ships with a capacity of 500 GRT, or more if not engaged in international trade [1].

The reason for developing and implementing the AIS was that the existing systems for detecting other targets, including the marine navigational radar, were far from perfect. What matters is the accuracy of calculated movement parameters and the time needed for parameter stabilization, which in case of the radar may take a few minutes. The situation is similar when a manoeuvre of a target is detected. This shortcoming may have an essential influence on the effectiveness of actions that have to be taken to prevent a collision, especially in restricted visibility, when the radar image cannot be confronted with visual observation [1]. Ship encounter parameters obtained from the radar are burdened with a considerable error. The accuracy of determined movement parameters and target approach to a large degree depend on the tracking filter used. Commonly used numerical filters based on the Kalman filtration are characterized by high accuracy of state vector estimation when the movement of the target is stable. During manoeuvres, however, the estimation accuracy is lower and tracking happens to be delayed. Once the AIS was introduced, the error of the calculated CPA (closest point of approach), as specified according to IMO tests, could be as much as 0.7 Nm and despite constant advancements it still oscillates around 0.3 Nm.

The method that can adjust the filter to varying parameters of ships in motion is the multimodel filtration, in which filter parameters are chosen to match the dynamics of vessel movement. Elementary filters used in such case may be both, numerical and neural filters. It is assumed that the application of this filtration method will reduce both, the detection time of target manoeuvre and tracking errors.

Aim of the research

The research done under the ministry-financed project MNiSW N N526 195038, headed by Witold Kazimierski, aims at developing methods of radar tracking of vessels by the application of multimodel neural filtration. Data recordings were carried out on board the training / research vessel "Nawigator XXI" in order to gather source information for the examination of real shipboard radars. 49 vessels were qualified for the recordings. Drifting, anchored or moored vessels were rejected and so were the recordings with insufficient amount of data.

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$RATTM,133,33.32,163.5,T,0.0,174.0,T,27.3,-600.0,T,0.9,-
    244.8,N,,T,,121537.00,R*35
$RATLL,02,5400.797,N,01426.598,E,,121539.00,T,*28
$RATLL,03,5359.927,N,01423.118,E,,121539.00,T,*2E
$RATTM,02,5.15,59.9,T,8.1,355.0,T,4.8,-13.9,N,,T,,
    121539.00,M*10
$RATTM,03,2.95,54.6,T,1.5,298.4,T,1.8,72.5,N,,T,,
    121539.00,M*36
$RATLL,101,5400.541,N,01426.723,E,NORSEMAI,
    121539.00,T,*11
$RATLL,102,5354.539,N,01415.967,E,PILOT,63,121539.00
    , T,*7E
$RATLL,103,5354.442,N,01415.581,E,URAN,121539.00,T,
    *15

$RATTM,120,34.27,163.6,T,0.1,197.5,T,27.5,-600.0,N,SM
    PRC 1,T,,121541.00,R*5B
$RATLL,02,5400.784,N,01426.617,E,,121543.00,T,*23
$RATLL,03,5359.920,N,01423.130,E,,121543.00,T,*2E
$RATTM,02,5.15,60.1,T,8.2,354.9,T,4.8,-13.6,N,,T,,
    121543.00,M*1B
$RATTM,03,2.95,54.8,T,1.6,299.5,T,1.8,69.9,N,,T,,
    121543.00,M*30
$RATLL,121,5324.807,N,01434.733,E,JULIETTA,121543.0
    0,T,*0C
$RATLL,122,5412.134,N,01336.963,E,,121543.00,T,*14
$RATLL,123,5351.398,N,01416.788,E,HEGEMANN,12154
    3.00,T,*1C
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Fig. 1. Data recorded on board the "Nawigator XXI"
Rys. 1. Dane zarejestrowane na pokładzie "Nawigatora XXI"

Altogether, 42168 NMEA strings were analyzed, an average of over 800 recordings per target. Figure 1 presents a sample of recorded data.

The lines marked as $RATTM (Radar Tracked Target Message) contain, respectively, the following information:

$RATTM,03,2.95,54.6,T,1.5,298.4,T,1.8,72.5,N,,T,,121539.00,M*36

03 – target number;
2.95 – distance to target;
54.6,T – rue bearing on target;
1.5 – target speed through water;
298.4,T – target heading;
1.8 – D_{min};
72.5 – $T_{D\min}$ (if marked by "–" targets passed safely);
N – speed unit – K [km/h], N [knots] or S [mile/h];
, , – target name, e.g. Target 1; in this case not assigned;
T – target status – L (lost), Q (query – introduced for tracking) or T (tracking);
121539.00 – UTC;
M – automatic acquisition – A, manual – M;
*36 – checksum preceded by a star.

The lines marked as $RATLL (Radar Target Latitude / Longitude) contain the following information:

$RATLL,03,5359.920,N,01423.130,E,,121543.00,T,*2E

03 – target number;
5359.920,N – target latitude;
01423.130,E – target longitude;
, , – target name, e.g. Target 1; in this case not assigned;
121543.00 – UTC;
T – target status – L (lost), Q (query – introduced for tracking) or T (tracking);
*2E – checksum preceded by a star.

The processing of results

The aim of on board ship tests was to verify the hypotheses formulated on the basis of simulations presented in [2, 3]. Five target categories were distinguished in terms of the rate of turn (ROT):

- up to 20°/min – stable movement or very slow manoeuvre;
- 20–30°/min – slow manoeuvre;

- 30–40°/min – manoeuvre;
- 40–55°/min – fast manoeuvre;
- more than 55°/min – very quick turn.

The ROT values were calculated from real data on the target course. Two methods were used:

1) instantaneous value was calculated by comparing the target course obtained from two successive NMEA strings;
2) mean value was calculated by comparing the present heading of the target with the averaged value of the latest minute data.

Table 1 presents the distribution of recorded targets' rates of turn, determined from the averaged value obtained by the two mentioned methods.

Table 1. Rate of turn of targets in degrees/minute
Tabela 1. Obrót obiektów w stopniach/minutę

Rate of turn range [°/min]	Targets [%]
0–20	81.2
20–30	7.6
30–40	3.5
40–55	2.5
over 55	5.2

The adopted categories follow the propositions set forth in [2, 3]. It should be noted that over 81% of targets belonged to the first category, i.e. targets turning with a rate ranging from 0 to 20 degrees per minute. Based on the divisions made in simulation tests [2, 3] those targets are considered as not manoeuvring or manoeuvering very slowly. In simulation tests that group included 68% of all targets. In field tests a similar percentage fits a range up to 14 degrees per minute. As far as first four categories are concerned, their percentage is the same for both types of study and amounts to approximately 95%. It seems reasonable to modify slightly the categories assumed in [2, 3] for the purposes of tracking filters development. The first category should include targets with a rate of turn up to 15 degrees/minute. The second group would range from 15 to 30 degrees/minute. The other groups should remain unchanged. Table 2 shows the new categories as proposed herein.

Table 2. Rate of turn of targets in degrees/minute
Tabela 2. Obrót obiektów w stopniach/minutę

Rate of turn range [°/min]	Targets [%]
0–15	69.1
15–30	19.7
30–40	3.5
40–55	2.5
over 55	5.2

The ranges for linear speed changes have be so selected that the number of targets in respective ranges is possibly similar. Table 3 presents targets changes of linear speed in time.

Table 3. Accelerations of targets in m/s^2
Tabela 3. Przyspieszenie obiektów w m/s^2

Range of accelerations [m/s^2]	Targets [%]
0–0.01	66.9
0.01–0.02	18.6
0.02–0.03	7.9
0.03–0.05	3.9
over 0.05	2.7

- up to 0.01 m/s^2 – stable movement or very slow manoeuvre;
- 0.01–0.02 m/s^2– slow manoeuvre;
- 0.02–0.03 m/s^2– manoeuvre;
- 0.03–0.05 m/s^2– fast manoeuvre;
- more than 0.05 m/s^2– very quick slowing down or acceleration.

The values of accelerations were calculated from data on target speed. Two methods were used:

1) instantaneous value was calculated by comparing the target speed obtained from two successive NMEA strings;
2) mean value was calculated by comparing the present speed of the target with the averaged value of the latest minute data.

In the proposed speed change ranges, almost 67% of targets were qualified to the first range of not manoeuvring or very slowly manoeuvring vessels, while the first four categories comprised more than 97% of targets.

Conclusions

The article presents the results of the processing of data recorded during real radar target tracking. Observations of both, linear speed and rate of turn changes, show that over 66% of targets qualify as non-manoeuvring or very slow manoeuvring vessels. In case of rate of turn changes almost 95% of targets belongs to one of the first four categories. For the linear speed the figure is roughly 98%, which may prove that the speed alteration manoeuvre is more difficult to detect than course alteration. This refers to radar and visual observation as well. Therefore, course alteration is the basic manoeuvre performed to prevent or avoid a collision situation at sea.

Based on the results of simulations [2, 3] and real tests at sea, targets can be categorized in terms of their dynamics. Besides, it is possible to estimate the probability that a target moving at a given rate of turn or linear acceleration belongs to one of the proposed categories.

The results of real tests have confirmed that the thresholds determined from simulation tests are correct and require only a slight adjustment concerning the first range. It seems reasonable to carry out further research to indicate a correlation or its absence between the alteration of linear speed and that of rate of turn.

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