Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2010, 22(94) pp. 18–22

2010, 22(94) s. 18–22

Target association in the process of tracking radar and AIS integration

Asocjacja obiektów w procesie integracji radaru śledzącego i AIS

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Key words: target tracking, radar–AIS integration, tracking radar

Abstract
The article presents issues connected with association of radar and AIS targets in the process of integration of this two systems. Theoretical analysis of the problem has been carried out. IMO requirements has been depicted and included in three association criteria proposed, which sequentially implemented in the algorithm allow firm association of radar and AIS targets. The general condition for association has been presented and it has been subsequently detailed for each criterion. As the basic test association of the position has been taken and it can be supplemented by association of movement vector and history of association in the furtherer steps. In each case the association gate has been defined. The sizes of gates, which allow to consider chosen criterion as fulfilled has been determined by analysis. The presented association algorithms may be used as the first step of radar–AIS integration to lead to multisensory vector fusion in the consecutive steps.

Słowa kluczowe: śledzenie obiektów, integracja radar–AIS, radar śledzący

Abstrakt
W artykule przedstawiono problematykę związaną z asocjacją obiektów radarowych i AIS w ramach procesu integracji tych dwóch systemów. Przeprowadzono teoretyczną analizę zagadnienia. Opisano wymagania IMO i z ich uwzględnieniem zaproponowano trzy kryteria asocjacji, które zastosowane sekwencyjnie w algorytmie pozwolą na jednoznaczne wskazanie przyporządkowanych obiektów z radaru i AIS. Przedstawiono ogólny warunek asocjacji, który następnie rozwinięto szczegółowo dla poszczególnych kryteriów. Jako test podstawowy przyjęto asocjację pozycji, która w kolejnych krokach może być uzupełniona o asocjację wektora ruchu i historii asocjacji w poprzednich krokach. W każdym przypadku zdefiniowano bramkę asocjacyjną. Na drodze analitycznej wyznaczono wielkości bramek, a więc konkretne wartości, które pozwolą uznać wybrane kryterium za spełnione. Zaprezentowane algorytmy asocjacji mogą stanowić pierwszy etap integracji obiektów śledzonych przez radar i AIS, aby w kolejnych doprowadzić do fuzji wektorów z obu systemów.

Introduction

The integration of tracking radar with Automatic Identification System (AIS) is necessary in modern navigational devices. The results of the integration can be presented either on the radar screen or on the electronic navigational chart or in any other navigational system. Regardless of the way of presentation the main goal of the integration is to avoid the situation in which the navigator receives two different movement vectors for the same target (AIS and radar vectors). Additionally the integration is to ensure that the vector shown is possibly the most accurate to receive. It this way the integration of tracking radar with AIS influences directly on the safety of navigation [1, 2].

The integration means determining of one movement vector for each observed target, based on the vectors calculated independently by radar and AIS. The integration can include only these dynamic information about the ship, which are delivered by both systems, like position, course and speed of the target [3].

There are a few algorithms for the process of integration, beginning with the simplest, like complementation one another of radar and AIS in the aspect of the targets seen, up to complicated multisensory numerical filters, that carry out vector fusion. In each of the algorithms there is a problem of target association, which leads to find the counterparts between the targets shown in both systems. During simultaneous observation with radar and AIS, the following situations could happen:

– Radar and AIS targets represent the same vessel,
– AIS target has no counterpart among radar targets (e.g. due to shadowing or too big range),
– Radar target is not shown in the AIS system due to lack of AIS transponder,
– Radar target is a false echo and has no counterpart among AIS targets.

Target association shows indirectly, which one of the above stated situation has to be considered in the analyzed case and allows further integration in the suitable way. After association the next steps of integration algorithm takes place.

IMO requirements

The radar-AIS integration issues in radar appliances has been stated in 2004 in the Maritime Safety Committee Resolution no 192 [4]. The Resolution is about performance standards for the radar equipment installed on ships after 1 July 2008. It is the first time, when references to AIS has been made in the aspect of radar equipment.

One of the requirements stated in the resolution says that each radar appliance should have the possibility of presenting AIS targets and the minimum required number of them depends on the GT of the vessel. There is a general requirement that AIS targets should be treated in the same way as radar targets, which is later detailed and the rules of presenting both radar, AIS targets and combination of them are explained.

The resolution introduces the term of *AIS and radar target association*. An automatic target association function based on harmonized criteria should be provided as it avoids the presentation of two target symbols for the same physical target. The assumption has been made, that if both radar and AIS target data are available and association criteria (e.g. position, movement, etc.) are fulfilled such that the AIS and radar information are considered as one physical target, then as a default condition, AIS target data and symbol should be automatically selected and displayed. The user should have however the possibility of changing the default condition to display radar target data and of selecting any of data for the single target. If radar and AIS target data are significantly different, the system should consider them as two separate targets.

Summing up the requirements of the resolution relative to radar and AIS integration it can be stated, that it is limited to selecting one of target data set (AIS is default), when both targets are considered to be the same object and to presenting both targets in case where there is no association between targets.

It should be expressed that Resolution MSC.192 (79) does not contain a specific association algorithm, but only exemplary association criteria like position or movement parameters. However the resolution is not giving any values or test scenarios. Instead of this the reference to the standard of International Electrotechnical Commission IEC 62388 has been made [5]. This standard treats the issues related with testing radar equipment to ensure compliance with MSC.192(79) [4].

Association criteria

The association of radar and AIS target should be based on finding such a similarity between them, which firmly indicates, that both systems describe in the target data the same object.

The most natural criterion for this purpose seems to be sameness of target's position. However due to errors of position determination it is possible, that this criterion will become not sufficient. It can even occur, that it is fulfilled for more than one object. In each of the situation mentioned above, it can happen, that the criterion of position will be fulfilled for the wrong target, what will cause incorrect association [6]. Thus it seems that there should be another criteria apart form position. The criterion of course and speed shall be introduced which is also equivalent to the criterion of movement vector in general. It may be also needed to confirm the association tendency in the period of time. Thus three association criteria are ultimately proposed:

– criterion of position,
– criterion of movement vector,
– criterion of history.

The general condition of association can be stated as the following:

$$|X_{\text{radar}} - X_{\text{AIS}}| \leq B \tag{1}$$

where: X – specific value calculated according to the criterion used (e.g. position, course), B – threshold determining the size of the association gate.

In the following part of the article the analytical considerations about determining of association gates size for each particular criterion.

Association of position

The first and the most natural criterion of association is the distance between targets. The algorithm assumes in this case the determination of the association gate for each radar target around its position. If one or more AIS target is detected inside the gate, the system accepts the fact, that the target is already tracked by AIS. If no AIS target is found in the analyzed area, the object is treated as a new and radar target data is being shown.

The association gate size can be found with the formula (2). For the simplification of calculations the sizes of the ships are not considered and the assumption is being made, that the position in both cases (radar, AIS) indicates the same part of the tracked target. Additional assumption is that radar position is delivered and measured at the same time as AIS position. Theoretically it is possible, however in practice it may be necessary to extrapolate radar position. It seems, that under the assumption of very small differences (probably a few seconds) linear extrapolation can be used.

$$B_p = \delta_1 + \delta_2 \tag{2}$$

where: δ_1, δ_2 are the errors of position determination with radar and AIS.

The value of δ_2 derives directly from the accuracy of the position fixing system used in AIS (probably GPS). If the association is being carried out in the moment of receiving AIS position, there are no additional errors of position due to time delay. The value of δ_1 depends on the distance of the object (range being used) and on the specification of the radar itself. It can be calculated with the following equation:

$$\delta_1 = \delta_o + \delta_D + \frac{2\pi D}{360}\delta_N \tag{3}$$

where: δ_1 – error of radar position [m], δ_o – error of determining own radar position. In the case of shore radar this error is neglect small [m], δ_D – error of range determination in radar [m], δ_N – error of bearing determination in radar [º], D – distance to target [m].

It shall be noticed that error of the position determination in radar depends on range being used, i.e. on the distance of the object. It means, that when the target's range is rising, the uncertainty of radar position δ_1 grows rapidly. This results also in enlarging of the size of position association gate B_p. The analytically derived values for the gate size are shown in the table 1. The error of AIS position is taken as 7 m. Radar errors were derived for each system from suitable standards and requirements. The gates are the smallest for shore radars and the biggest for maritime radars. It can be seen that, if the target is located at 10 Nm the association gate for maritime radar should have a size of almost half of nautical mile. It means that at least a few of small targets can be easily found in such a large area. The gate size seems to be however reasonably small for closer targets.

In this situation it seems, that for greater ranges of objects, it would be better to use polar coordinates for position association. Distance association gate B_D can be in this situation calculated from:

$$\begin{aligned} B_D &= \delta_{D1} + \delta_{D2} \\ \delta_{D2} &= \delta_o + \delta_2 \end{aligned} \tag{4}$$

where: δ_{D1} – error of determining range in radar [m], δ_{D2} – error of determining range in AIS [m], δ_o – error of determining own radar position. In the case of shore radar this error is neglect small [m], δ_2 – error of target position determination with AIS [m] – same as in (2).

Table 1. Position association gate sizes for the different radar systems and distance to target
Tabela 1. Wielkość bramki korelacji pozycji dla różnych systemów radarowych i odległości obiektu

SYSTEM \ DISTANCE	1000 m	1 Mm	10 Mm
Maritime radar	99 m	129 m	851 m
River radar	46 m	73 m	611 m
VTS radar (acc. to IALA [7])*	49; 58; 77 m	58; 70; 96 m	232; 302; 474 m

* for different accuracy levels according to IALA

The size of association gate for bearing B_N can be calculated as:

$$B_N = \delta_{N1} + \delta_{N2} \tag{5}$$

where: δ_{N1} – radar bearing error [º], δ_{N2} – AIS bearing error [º].

It should be added, that AIS bearing error is inversely proportional to the target range. When the distance is less than 1 nautical mile, the error begins to grow rapidly, as the error of position not distance becomes crucial. Thus it can be stated, that for very close targets it is better to use position association according to (2), and for greater distances according to (4) and (5). It has to be also added that range, not bearing should be the first association criterion of position, because radar distance measurement is more accurate than bearing measurement.

Association of movement vector

The second stage of radar and AIS target association process is *movement vector association*. It can be a very good additional criterion supplementing position association. In this situation position association becomes necessary but not sufficient condition for target association. The simplest but efficient method of movement vector association is to analyze target course and speed separately.

It should be now reminded that AIS and radar provide usually different stabilization of course and speed. AIS always shows target's speed and course over ground, while radar usually target's course and speed through the water. It is however possible to stabilize radar picture over ground with external positioning system or fixed target. Thus the assumption has been made that radar has been stabilized over ground and association gate size can be established for the values over ground. If course and speed over ground from AIS and radar are known, the association gates can be obtained with the formulas (6) and (7).

$$B_C = \delta_{C1} + \delta_{C2} \tag{6}$$

where: δ_{C1} – radar's COG error [°], δ_{C2} – AIS' COG error [°].

$$B_V = \delta_{V1} + \delta_{V2} \tag{7}$$

where: δ_{V1} –radar's SOG error [kn], δ_{V2} – AIS' COG error [kn].

Table 2. Course and speed association gates sizes for different radar systems
Tabela 2. Wielkość bramek korelacji kursu i prędkości dla różnych systemów radarowych

System	Speed association gate [kn]	Course association gate [°]
Maritime radar	0.9 or 1% of speed + 0.4	7
VTS radar (acc. UNECE [8])	0.9	7

If accuracy of COG and SOG calculated by radar comply the requirements for radar tracking and COG and SOG delivered by AIS errors are 2° and 0.4 knot, the association gate has dimensions shown in table 2. The values are presented for maritime and VTS radars. The course association gate have the same size, but speed association gate is smaller for shore systems. The values seems to be reasonable also from the practical point of view.

It is possible to reduce the number of necessary mathematical calculations, by introducing the term of movement vector, which can be defined as:

$$\mathbf{u} = [\text{course, speed}]^T \tag{8}$$

or in the Cartesian coordinates

$$\mathbf{u} = [Vx, Vy]^T \tag{9}$$

The association gate takes then a form of association vector (10):

$$\mathbf{B_u} = \begin{bmatrix} \delta_{C1} + \delta_{C2} \\ \delta_{V1} + \delta_{V2} \end{bmatrix} \tag{10}$$

where: δ_{C1} – radar's COG error [°], δ_{C2} – AIS' COG error [°], δ_{V1} –radar's SOG error [kn], δ_{V2} – AIS' COG error [kn].

Association of history

The target association based on once-in-time checking of presented association criteria is not always sufficient and may lead to failure of integration process. It is not so hard to imagine the situation in which associated targets separate from each other and continue moving in completely different directions and the association is the result of temporary and occasionally sameness of movement parameters in close position. This is why *association of history* should be considered, as third stage of association algorithm. It's goal to check if target association has been maintained in the period of time. It is then to confirm association tendency in a few consecutive steps by eliminating casual association. The similar situation occurs in tracking filters, which are looking for the target in the tracking gate to confirm its movement. If the target is not there loss of target is considered. However this tendency has to be confirmed in further steps.

The commonly used approach is to establish, that if a target fulfill the criterion in *N* of *M* consecutive steps, the tendency is considered to be stated and the association is valid. The accurate values of N and M can be established by adopting the values from radar tracking systems. Then criterion of history association could be 3 of 5 steps (as at the track initiation) or 5 of 10 steps, as in lost target warning.

3 of 5 steps criterion seems to be sufficient, although due to rare time sampling of AIS information for anchored ships (3 minutes), additional time limit may be considered (e.g. confirmation of tendency after one minute). Another (simpler) solution

is to quit history criterion for the targets with speed less than 2 knots, for which radar shows zero vector on the screen.

The history criterion should be used after association of position and movement vector. Using of it leads to one of four possible decision about association. It is being initiated, continued, discontinued, deleted.

Conclusions

The article presents problem of radar and AIS target association in the process of radar-AIS integration. As a first step of such an integration, target association is of crucial meaning, deciding whether the integration and possibly vector fusion should be made or not.

The possible situations that may occur during target integration have been shown and IMO requirements has been discussed. Three association criteria have been proposed. For each of them a short analysis has been presented supported with theoretical consideration on the sizes of association gates.

The proposed algorithm consisting of three steps of association should allow to find among AIS and radar target the, so called, associated target. There are however a few additional criteria that can also be included in more complicated association algorithms. These are:

- size of object – unfortunately determined very roughly in radar, however some conclusions can be made based on tracking gate size or detection range;
- dynamic and variability of the movement – criterion hardly limited by commonly known radar tracking delays.

It has to be pointed out, that gate's sizes proposed in the article derives from the theoretical analysis and should be confirmed in the empirical research. After successful target association the integration algorithm can be continued in the specific for the chosen algorithm way.

The association of AIS and radar targets is necessary not only according to requirements, but also from the practical point of view. It is the first step of vector integration process. The idea of association is to create a gate around the target data. The crucial task is then to determine proper size of this gate. It has to be small enough to avoid false association, but large enough to include system errors. The size of the gate can be determined analytically as in this paper. It could be however very interesting to supplement this values with the results of empirical research.

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