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DEDUPLICATION OF TRACKED OBJECTS POSITION DATA AT SINGLE OBSERVATION POINT OF A VESSEL MONITORING SYSTEM

ABSTRACT

Vessel Monitoring System (VMS) play a major role in safety navigation. In most cases they are based on two data sources, namely Automatic Identification System (AIS) and Automatic Radar Plotting Aids (ARPA). Integration of data obtained from these sources is an important problem, which needs to be solved in order to ensure the correct performance of a given VMS. In this paper basic functions which should be implemented in a tracked objects position data deduplication module are described. An example based on their practical implementation is also presented.

Key words:
Vessel Monitoring System, deduplication of position data, fusion of AIS and ARPA data.

INTRODUCTION

Reliable identification of vessels and a safety of navigation are becoming more and more important aspects for most of the maritime countries. Achieving these goals is much easier with the help of Vessel Monitoring System (VMS). In a typical

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case, such a system is based on data obtained from two sources: Automatic Radar Plotting Aids (ARPA) and Automatic Identification System (AIS) [6].

With the use of the first one, even targets that are untraceable by AIS (e.g. because of lack of an AIS transmitter on-board) can be detected. However, weather conditions play an important role in radar performance. Moreover, its area of coverage is limited due to the blindness and shadowing effects. AIS-based data are usually more accurate and detailed. Also, in the typical case, the area which is covered by the AIS receiver is larger than the one which may be achieved with ARPA equipment. However, the main disadvantage of AIS-only based objects tracking is the ability to detect only these ships, which are equipped with AIS transmitter. It needs to be pointed out, that such data have to be treated with some level of distrust, since the AIS message depends on the target ship's transmitter configuration and its content sometimes does not coincide with the facts (some information may be incorrect due to unintentional or intentional actions). For these reasons, data obtained from both sources need to be combined together, which is usually done in such a way that ARPA radar is in priority and AIS receiver is treated as supplementary data source [3, 6].

Already mentioned AIS and radar data fusion is quite complicated due to the differences of tracking methods and their performance, target data category and position data precision. Several approaches are known though, e.g. these given in [1, 4, 5, 8, 9]. However, most of them are quite complex in terms of required computational power. The next sections of this paper are meant to:

- discuss the typical problems in a fusion of AIS, GPS and ARPA data;
- propose some low-complexity solutions for these problems;
- present the results of a practical implementation of the mentioned solutions.

PLACE AND ROLE OF AN OBSERVATION POINT

In order to increase its operational range, the vessel monitoring system structure is often based on distributed mobile observation points, e.g. vessels, aircrafts or land vehicles. Collecting data obtained from these points in a single central database is also often desired. Such database may be included in a central observation point located on land. Besides receiving the data sent via radio channel by already mentioned observation points, it may also obtain another data stream from some external source, e.g. independent radar network. Such data may be available via wideband WWW service. Described VMS structure is exposed to duplication of tracked objects position data caused, among others, by:

- tracking the same object by many local devices in a single observation point;
- receiving similar data from a central server in a single observation point;
- receiving similar data from many observation points in a central server.

The rest of this paper will cover just the first cause. Structure of a typical mobile observation point is shown in figure 1.

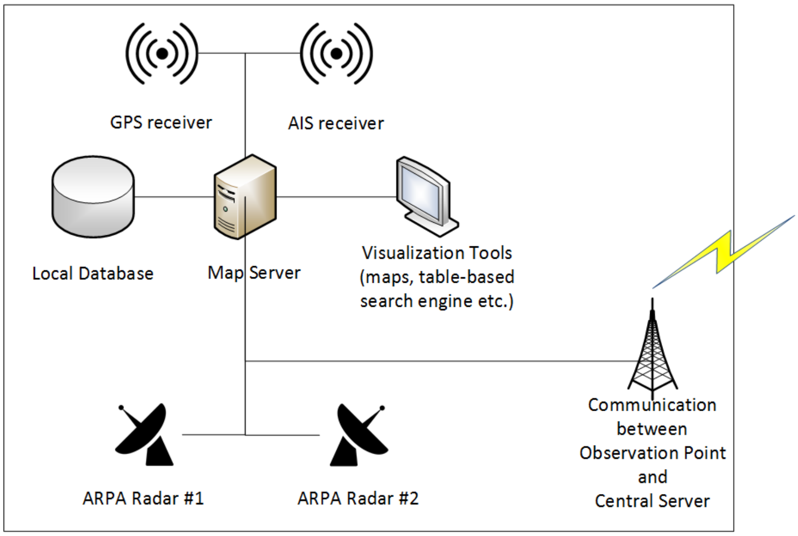

Fig. 1. Structure of a typical mobile observation point

It can be seen, that the tracked objects data are provided by an AIS receiver and ARPA radars (it was assumed that two radars of such kind may be installed in single mobile observation point). In addition, a GPS receiver is used to report the position of an observation point and provide time synchronization. The data are obtained from those devices in the form of AIS messages, defined in recommendation [10] and radar/GPS packets, characterized in NMEA 0183 standard [7]. Next, they are processed in a map server (dedicated software responsible for data analysis and exchange) and inserted into the local database, which may be accessed by visualization tools through the same map server. Communication between mobile observation point and a central server is based on the corresponding radio link. Further parts of this paper relate to the map server software, in particular to functions which should be implemented in the input data deduplication module (whereas 'deduplication' means removing the redundancy present in the input data streams).

DEDUPLICATION OF TRACKED OBJECTS POSITION DATA

As it was mentioned before, the problem of duplication of tracked objects position data, occurring in a single mobile observation point, is caused by the fact that many tracking devices (e.g. AIS receiver and two ARPA radars) may send data referring to the same object at approximately the same time. Such data streams may differ both in sense of available information and determined objects position coordinates (i.e. latitude, longitude and time stamp). Moreover, each device may be characterized by its own position-fix accuracy and frequency of providing new data (which is usually constant in case of ARPA radars and variable in case of an AIS receiver). While choosing a way to solve this problem, one should also take into account the potential application, e.g. determine whether deduplication needs to be provided in real time before sending the data to the visualization tools or if it can be realized later (i.e. introduce significant latency). Hereafter, a low-complexity solution is going be described, which makes it possible to remove the redundancy in real-time, before inserting the data into a local database (and requesting them later by the visualization tools).

In general, the problem of duplication of position data may be considered in a multi-dimensional space. Dimensions of such a space should be determined by these parameters, which may be obtained from all tracking devices (AIS receiver, GPS receiver, ARPA radar) for the same tracked object. Time of fixing an object position, latitude and longitude are a natural choice which forms a three-dimensional space. The object's speed over ground and a course could be another potential dimensions. However, poor accuracy and reliability of determining their values by different devices is a limitation, which rather excludes them from being considered as deciding factors. Thus, the following analysis will be limited to already mentioned three-dimensional space.

The way of solving this problem can be based either on evaluating the matching of parts of objects tracks or on evaluating the matching of particular track points (elements of a track) separately. The latter approach is much easier to implement. In this case, deduplication module needs to decide which of the input track points should be rejected due to detected duplication. Such decision can be reduced to searching of any other object track points in the nearest area of currently analyzed track point in three dimensional space. The decision should be made as follows: if at least one other object track point is located inside such a duplication area, then one of them should be rejected. Concept of this approach is illustrated in figure 2. Of course, making this kind of decision requires data buffering, which introduces some constant delay before inserting the data into database (such buffering is necessary, because, for example, AIS-based track point referring to some object may be received few seconds after receiving ARPA-based track point referring to the same object). Such buffer length, as well as the size of the duplication area, strongly depend on the characteristics of equipment used in observation point and dynamics of motion of tracked objects, so they should be determined in an experimental way. Still, one should keep in mind the compromise between improving the algorithm's performance and a negative results of choosing too large values (significant delay means that the situation shown on maps will no longer be current, while too big deduplication area will increase size of so called dead zone, in which even track points of different objects may be recognized as duplicates and finally rejected).

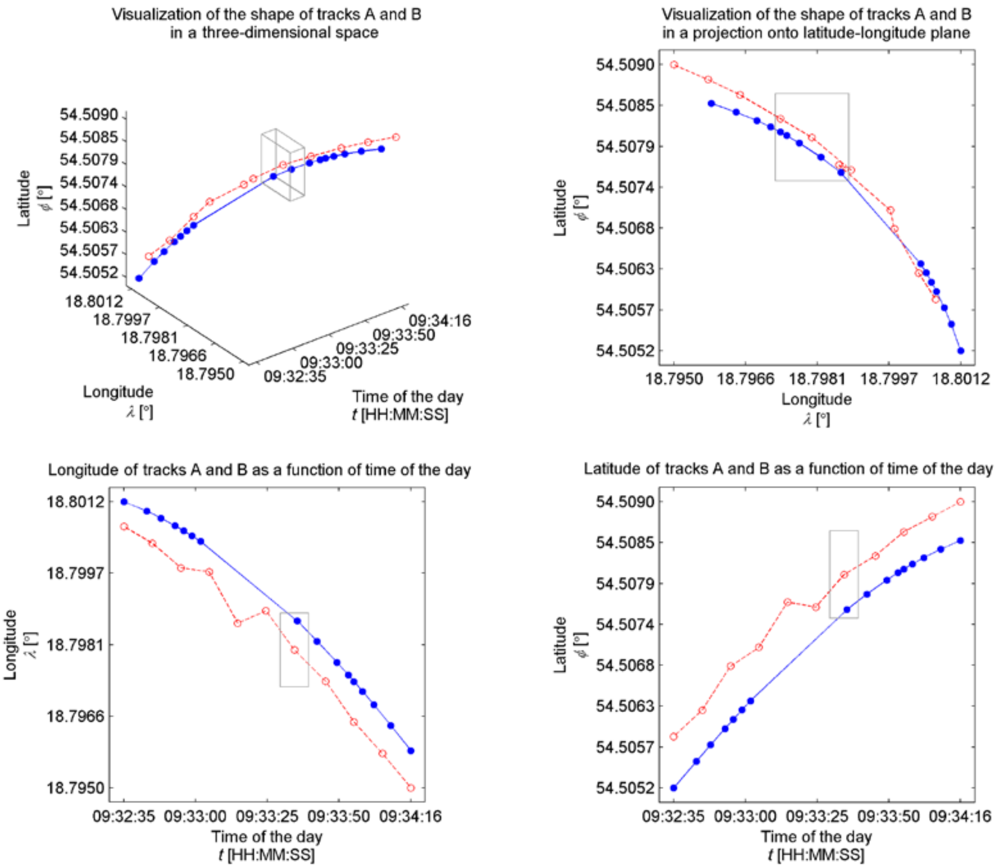

Fig. 2. Illustration of the deduplication of tracked objects position data
(blue solid line and red dashed line shows the shapes of the tracks A and B, respectively,
while solid gray line is used to mark the duplication area)

Analyzing longer parts of tracks may lead to even better results. In such approach, while deciding if a particular track point should be accepted or not, deduplication module may also take into account several previous decisions (e.g. if current decision shows no duplication, but in a set of five recent decisions there are at least three which showed duplication, then the current track point should also be treated as a duplicate and therefore rejected). Analogous hysteresis may be applied for changing status from no duplication to duplication as well. Such approach allows to reduce the risk of making the incorrect decisions caused by instantaneous deviations in determining the objects positions by ARPA radars (much less often by AIS and GPS receivers).

ADDITIONAL FUNCTIONS OF DATA DEDUPLICATION MODULE

This section describes additional functions, which should be implemented in a tracked objects position data deduplication module.

Identification of tracked objects is the first of such functions. The IDs of objects tracked by AIS receiver can be based on their MMSI (Maritime Mobile Service Identity) within the range of 0 and 999 999 999 [10]. Moreover, some specific range of IDs may also be restricted in the whole system for the purpose of identification of the mobile observation points (e.g. the range of 1 000 000 000 and 1 000 000 100). The rest of IDs may be used to identify objects tracked by ARPA radars, whereas they should be divided between all the radars in VMS in such a way, that the range of IDs used on some particular radar cannot be used by any other radar.

Time synchronization of tracked objects position data, obtained from different sources, is another problem. The system clock of a computer on which the map server is running on may be synchronized via GPS receiver. This solves the problem for ARPA and coupled GPS data — time of receiving of corresponding packet may be used as time of fixing the object's (or observation point's) position. However, some AIS messages contain additional time stamps of fixing the object's position determined by the AIS transmitter [10]. In some cases, full UTC time stamp is provided (YYYY-MM-DD hh:mm:ss). Then, if the difference between time of receiving this AIS message and the mentioned time stamp is acceptably low, the latter may be used directly as time of fixing the object's position in the VMS system. In other cases, only UTC seconds are available (ss). Then the full time stamp (YYYY-MM-DD hh:mm:ss) needs to be recovered on the basis of this information and the local system clock (i.e. time of receiving of AIS message). Once again, recovered time stamp should only be used if the difference between its value and time of receiving the AIS message is acceptably low. Otherwise, using of the latter is safer (such approach takes into account a possibility of an incorrect synchronization of AIS transmitter clock).

In a typical case, during single rotation of its antenna period, ARPA radar sends at first a series of TLL (Target Latitude and Longitude) radar packets, containing, among others, geographical coordinates and statuses of all targets which were tracked during this period. After that, it sends a series of TTM (Tracked Target Message) radar packets, containing other useful information about those targets [7]. Processing of these data in other VMS modules becomes much easier if TLL and TTM packets will be joined together for each tracked target and sent forward in a form of a single system packet containing all necessary data obtained from ARPA radar. Implementing of such function requires data buffering, which is by definition already introduced in the data deduplication module, so it is beneficial to implement such function in this module as well.

Depending on the system application, some of the packets fields are crucial and must contain correct values (e.g. time of fixing the object's position, geographical coordinates, etc.), while sending incorrect or empty values of other fields may be less harmful (e.g. altitude sensor type, maximum present static draught etc.). AIS messages containing incorrect values of some fields may in particular be quite often seen (e.g. cases of sending of incorrect rate of turn and true heading values are known [3], while own observation confirmed that occasionally also other parameters can be incorrectly set). Thus, various filters need to be implemented in order to verify the packets' contents in many different ways. In case of detection of some anomaly, input packets may be forwarded or rejected with an optional display of a corresponding warning, depending on the nature and harmfulness of such anomaly.

Typical radar antenna rotation period is about few seconds (e.g. 2–3 [s]). It means that such radar (and, optionally, coupled GPS receiver) is going to send new packets containing information about all tracked targets equally often. Such rate of generating new data has a great impact on required database size. Moreover, it may be unnecessarily high from the point of view of visualization tools (e.g. if the situation on a map is refreshed every 10 [s]). Therefore, some rate limiting mechanisms should be considered (e.g. rejecting all radar packets except these coming from every N-th antenna rotation period or rejecting position data obtained from subsequent antenna rotations if they are too similar).

ARPA radars often start sending packets containing the data of particular target right after that target was detected (this detection may be automatic or manual). It should be pointed out, that for the first few seconds (sometimes over a dozen) such targets are in the process of acquisition (their status is set to query). Moreover, they should be treated as not confirmed (depending on radar configuration and sensitivity, even reflection from waves may be displayed and tracked as a detected targets), and because they are often quickly lost it seems like a good idea to ignore all targets until their status will be changed to tracked [7]. Such approach allows us to eliminate most of very short tracks (containing only few track points and sometimes even a single one).

In case of a GPS receiver (and also, though much less often, an AIS receiver) it may happen that multiple packets containing the same geographical coordinates of some particular object and slightly different rest of contents are received at the same time (these packets have identical or slightly different time stamps then, e.g. differing by one second). For example, one of such packets may contain object's speed over ground while the other does not, or the object course value may be slightly different in both packets. In such situations, all of these packets should be joined together and forwarded to the next VMS system module in the form of a single resultant packet.

MODEL REALIZATION AND TESTING

The tracked objects position data deduplication module was successfully implemented as a part of a map server software written in C++ programming language [2].

Example of its main function, i.e. removing the redundancy present in input data streams, is shown in figure 3. These input data were recorded during the measurement campaign carried out in the Gulf of Gdańsk in March, 2014.

Object identified as 9JMMLC was tracked by an AIS receiver, while other visible targets were detected by an ARPA radar (such one to many assignment is typical in this kind of situation). Dimensions of the deduplication area were as follows: 0.00175 [°] × 0.003 [°] × 40 [s] (longitude, latitude and time of day, respectively) and a total delay introduced by deduplication module was equal to 20 [s]. As it can be seen, for such configuration all radar-based duplicates of the track of an object tracked with AIS receiver were successfully removed, which is a highly desired situation.

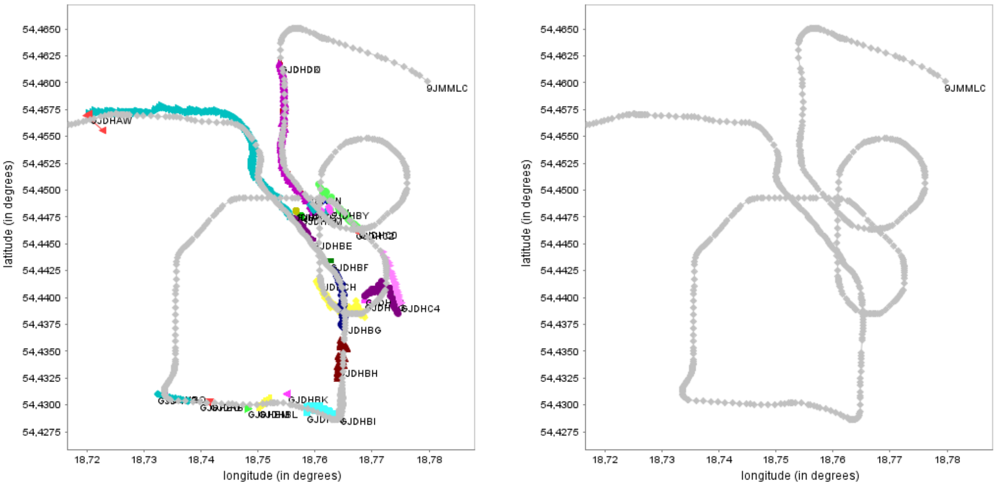

Fig. 3. Multiple tracks of one detected object (on the left) and its single track after data deduplication (on the right)

It should be pointed out that presented operations does not affect the possibility of tracking real objects traveling in the operational range (e.g. object tracked only by ARPA radar will not be rejected in deduplication module as long as there are no other objects in its nearest area).

CONSLUSIONS

In this paper, basic problems occurring in the field of tracking objects by AIS receiver and ARPA radars in single observation point of a vessel monitoring system were described. The implementation aspects of identification of such objects and deduplication of their position data were discussed as well. Obtained results showed that the presented methods may be successfully implemented in many specific applications. Future work will be focused on improving the performance and speed of the proposed algorithms, as well as testing them in real operational conditions.

Acknoledgements

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DEDUPLIKACJA DANYCH POZYCYJNYCH OBIEKTÓW NAWODNYCH ŚLEDZONYCH W POJEDYNCZYM PUNKCIE OBSERWACJI

STRESZCZENIE

Systemy kontroli i śledzenia ruchu statków w znacznym stopniu zwiększają bezpieczeństwo nawigacji morskiej. W większości przypadków bazują one na danych pozyskiwanych z dwóch źródeł: AIS (*Automatic Identification System*) i ARPA (*Automatic Radar Plotting Aids*). Integracja tego typu danych stanowi jeden z istotnych problemów, koniecznych do rozwiązania w trakcie implementacji wspomnianych systemów. W artykule scharakteryzowano podstawowe funkcjonalności, które powinny zostać zaimplementowane w module deduplikacji danych pozycyjnych śledzonych obiektów, a także przedstawiono przykład ich praktycznej realizacji.

Słowa kluczowe:

system monitoringu statków, deduplikacja danych pozycyjnych, fuzja danych z AIS i ARPA.