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REAL-TIME GENERATOR OF AIS/ARPA/GPS DATA

ABSTRACT

The paper presents a real-time generator of AIS/ARPA/GPS position data in the standardized NMEA 0183 text format. Position data are produced by a set of various types of ships simulated on the Polish part of the Baltic Sea and are generated on defined IP/UDP addresses and RS-232 ports. In the simulation an extensive set of input parameters is taken into account including the number of particular types of ships, their dimensions, speed as well as parameters of AIS equipments, ARPA radars and GPS receivers. The paper describes the architecture and implementation of the generator. Additionally, it demonstrates the application of the developed generator to test the software developed for the Polish Border Guard.

Key words:
AIS, ARPA, GPS, NMEA 0183, real-time generator.

INTRODUCTION

The real-time generator of AIS/ARPA/GPS data described in this paper was developed under the grant [3], which main aim is to implement the device providing voice communication and visualization of objects tracked by the Polish Border Guard (PBG) [3]. This device (called 'the console') was implemented in two variants: mobile (for PBG officers in ships, cars and airplanes) as well as stationary (for PBG officers in land centers).

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The role of the AIS/ARPA/GPS data generator is to simulate movement of PBG ships and tracked ships on the Polish part of the Baltic Sea as well as produce position data streams according to AIS (Automatic Identification System), GPS (Global Positioning System) and ARPA (Automatic Radar Plotting Aid) radar specifications [4, 10, 12] in real-time. These position data streams are formatted as standardized NMEA 0183 (National Marine Electronics Association 0183) [13] text strings and sent to RS-232 serial ports. The above mentioned data can be used to test database systems as well as deduplication, synchronization and presentation mechanisms in the software developed under the grant [3].

In the next part of the paper details regarding the implementation of the AIS/ARPA/GPS data generator are provided. Subsequently, tests of the software developed under the grant [3] using the generator are described. At the end the paper is summarized.

IMPLEMENTATION

Assumptions and requirements

The first important task for the AIS/ARPA/GPS data generator is to simulate movement of PBG ships and tracked ships on the Polish part of the Baltic Sea. It is assumed that tracked objects are represented by large ships with class A AIS equipment [12]. Two categories of these objects with different sets of parameters are considered. Information about position of tracked ships are gathered by the following PBG tracking units:

– PBG ships with AIS receivers and ARPA radars (radars are optional; maximum one radar per one PBG ship is assumed);
– AIS receiver network of Maritime Authority in Gdynia located at the Polish coast of the Baltic Sea (position data provided by the Web Service; it is assumed that these data concern the whole simulated part of the Baltic Sea and are distributed as AIS packets).

The simulated fragment of the Baltic Sea is approximated by a rectangle, which is defined by the following coordinates: 54,5°N–55,22°N; 13,8°E–20,8°E. It assumed that both PBG ships and tracked ships sail straight lines and may periodically change speed according to defined random variables. Tracked ships generate AIS position data during movement (according to AIS standard [12]), which are gathered by PBG ships receivers with limited range (defined in simulation parameters) and definable packet loss probability. PBG ships may also have ARPA radars installed to collect additional position information about tracked ships (for radars we also can define range and information loss probability). Contrary to AIS position data (which for the same tracked ship are identical in all PBG ships), information gathered for one particular tracked object by different ARPA radars may differ from each other. This is caused by azimuth and distance measurement errors (definable parameters), which are generally different for different radars. Additionally, particular ARPA radars independently assign identifiers (target numbers) for tracked ships and in most cases the same tracked ship will have different identifiers assigned by different radars. The result of the generator are the following position data streams in standardized NMEA 0183 format:

– data generated by PBG ships (one stream per one PBG ship, which allows testing the software installed in PBG ships [3]) containing:
  - AIS data received by PBG ships with definable range and loss probability,
  - data from ARPA radars installed on PBG ships (definable range and errors of radar are taken into account),
  - GPS data with position of PBG ships;
– AIS data from Maritime Authority in Gdynia (Web Service) — one stream from the whole simulated part of Baltic Sea, which allows testing the software installed in land centers [3].

It is assumed that the AIS/ARPA/GPS data generator may work in both graphical (GUI) and text mode. Graphical mode provides visualization of the simulated objects and allows detailed analysis of generated position data. In text mode the amount of available information is very limited, however, it consumes less processor resources and allows simulating more objects.

Structure of the source code

The AIS/ARPA/GPS data generator was implemented in the OMNEST [8] simulation framework (commercial version of OMNeT++). This choice resulted from the flexibility of this framework, very good documentation, possibility of applying standard C/C++ libraries, support for running applications in graphical mode (Tkenv) and command-line text mode (Cmdenv) as well as our previous experience. In the OMNEST framework simulated objects (called modules), their parameters and connections between them are defined using NED (NEtwork Description) language [9]. Basic operations in the developed application are performed by simple modules, which functionality is described using C++ programming language. Simple modules may be grouped to form compound modules, which perform more complicated functions.

Structure of the generator software is depicted in figure 1. Objects tracked by PBG (large ships) are represented by the duzy_statek simple module. PBG ships are implemented in the jedn_plywaj simple module. In the generator very important is also the global module, which is responsible for providing other modules with values of global variables (through global functions). It also receives AIS/ARPA/GPS data from PBG ships and AIS data from the um_gdynia simple module representing the WebService of Maritime Authority in Gdynia. Position data gathered by the global module are converted from internal format used in the generator (messages – C++ objects) to standardized NMEA0183 text strings and sent over IP network to ServerUDP_RS applications. Each of the ServerUDP_RS applications operates on separate UDP socket (pair of IP address and UDP port), receives one position data stream and sends it to a defined RS-232 port.

Global functions of the global module are used by other modules of the generator both before starting to simulate movement of objects and during this simulation. In the first case they are used for example to set initial geographic positions of objects. In the second case global functions of the global module are invoked among others to get new values of object speed.

According to the specification of the OMNEST framework [9], each simple module of the generator has implemented handleMessage() callback function, which is responsible for handling all messages incoming to this module. Incoming messages can be sent by the simple module itself or by the other modules. In the first case these messages are called selfmessages. Due to the fact that these type of messages is delivered in a specific simulation time, they are very useful for managing and synchronizing events, which allows realization of key generator functionalities such as object movement and generating position data in a proper simulation time.

Apart from handleMessage() function, in the generator also initialize() and finish() functions are used, which allow performing some operations at the beginning and end of simulation. These operations involve for example setting initial object parameters and deleting dynamically created objects at the end of simulation.

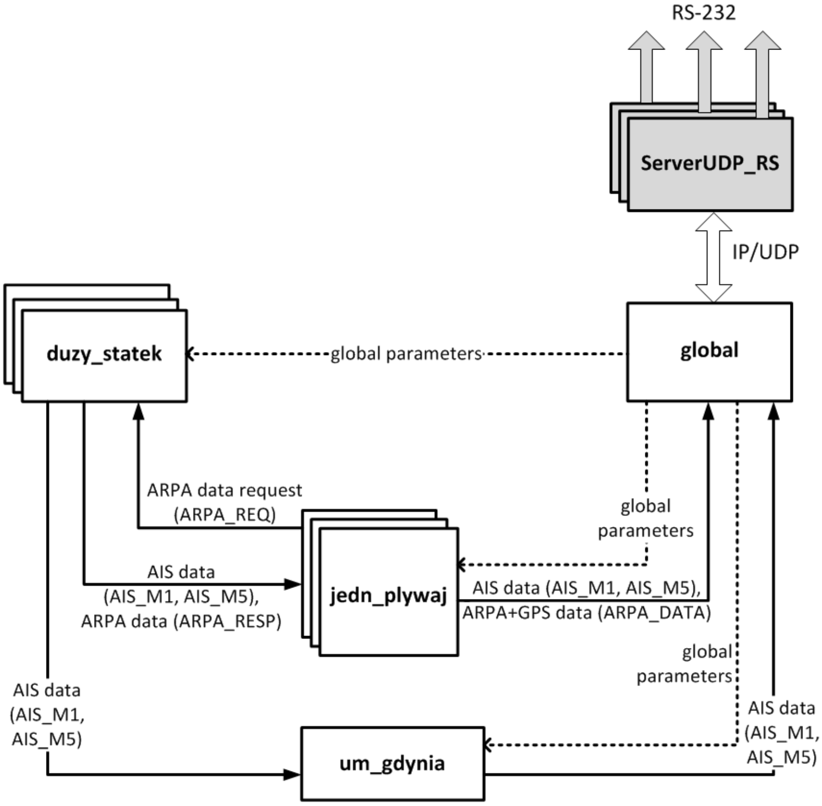


Fig. 1. Structure of the real-time generator of AIS/ARPA/GPS data; solid lines with arrows represent messages exchanged directly between modules, dashed lines with arrows — parameters passed using global functions of the global module; ServerUDP_RS applications cooperate with the generator and are not its integral part

Implementation details

The described AIS/ARPA/GPS data generator is based on the OMNEST real-time scheduler (cRealTimeScheduler [9]), which synchronizes simulation with real (wall clock) time. It is assumed that changes in objects speed are allowed only periodically, where the above mentioned period is a multiple of a definable time called the quantum time. Before starting the simulation a definable number of seaports is put randomly on the border of the simulated part of the Baltic Sea. Subsequently, source and destination seaports are assigned to duzy_statek objects. After reaching its destination port, a tracked ship (duzy statek object) stays in it for a period of time defined by a random variable and starts a new cruise to a new randomly assigned destination port.

For PBG ships (jedn_plywaj objects) there are three homeports located at the Polish coast and a definable number of virtual ports spread uniformly over the simulated sea area. A homeport is assigned to a particular PBG ship before starting a simulation. During the simulation each PBG ship stays in its homeport for a time defined by a random variable and starts sailing between random virtual ports. The time of sailing is also defined by a random variable. After this time a PBG ship returns to its homeport and the whole described procedure is repeated.

As already mentioned, large ships (duzy_statek objects) have class A AIS equipment installed (not all of them, it is defined in simulation parameters) and generate AIS position messages (figure 1) with intervals and content are defined in the AIS protocol specification [12]. Generated messages carry static and voyage related data (AIS protocol message 5 represented by the 'AIS_M5' message in the generator) as well as position reports (AIS protocol message 1 represented by the 'AIS_M1' message in the generator). These messages are sent directly (sendDirect() function) to all PBG ships and to the um_gdynia module representing the Web Service. For PBG ships a definable AIS receiver range is taken into account (messages out of range are deleted). From messages that are in range some are also deleted according to message loss probability, which can be defined in simulation parameters. Messages, which are not deleted, are sent to the global module.

For the um_gdynia module there is no defined range (the range is assumed to cover all simulated fragment of the Baltic Sea), but there is message loss probability similar to the case of jedn_plywaj objects (PBG ships). Before sending to the global module, AIS messages in the um_gdynia module may be additionally delayed, which reflects the time necessary to gather and process data.

In order to generate position data from ARPA radars each PBG ship with ARPA radar (the number of PBG ships with radars is definable) periodically sends (with definable intervals representing radar rotation time) messages called ARPA data requests ('ARPA_REQ' messages in figure 1). These messages are sent directly to all tracked objects (large ships) and contain among others the identifier (OMNEST module ID [9]) of the PBG ship generating the message. The attached identifier allows responding with an 'ARPA_RESP' message including the identifier (module ID), position and speed of the tracked object (duzy_statek module).

Based on the received 'ARPA_RESP' message PBG ship identifies the tracked object and reads its previous position from memory (if it was previously in radar range). Subsequently, comparing the previous and current object position, PBG ship assigns a new target number to a new object, holds the target number for the previously seen object or releases the target number when the object was previously visible and now is out of range.

After assigning or holding a target number, azimuth and distance measurement errors (parameters given by definable random variables) are introduced to tracked object position. Such modified coordinates are stored until 'ARPA_RESP' messages are received from all simulated duzy_statek objects. Then, for all tracked objects, stored data are used to determine fields of ARPA TLL (Target Latitude and Longitude) and TTM (Tracked Target Message) packets [4, 13]. This information is put into the 'ARPA_DATA' message along with the position and speed of the tracking PBG ship, which are needed to generate GPS RMC (Recommended Minimum Navigation Information) packet [13] concerning the PBG ship. The 'ARPA_DATA' message with ARPA and GPS data can be now sent directly to the global module (figure 1).

Definition of structures of all messages used in the generator for communication between modules are performed according to OMNEST documentation [9] in *.msg files. These files are during compilation of the AIS/ARPA/GPS data generator converted to C++ code and subsequently to executable code.

As already mentioned, the global module receives AIS/ARPA/GPS position data from jedn_plywaj and um_gdynia modules representing PBG ships and the Web Service of Maritime Authority in Gdynia. The first action taken for all received position data is to determine the output stream number, which is based on the sending module identifier. For N PGB ships by default N+1 position data streams are generated:

– streams from 0 to N–1 contain data gathered by particular PBG tracking ships (AIS and ARPA+GPS data);
– stream N contains AIS data provided by the Web Service of Maritime Authority in Gdynia.

In the next step messages received by the global module are converted form internal generator format (C++ objects) to standardized NMEA0183 text strings. For this reason dedicated external functions are used: create_VDM(Message_ID) for AIS messages of type 1 and 5, create_TLL() and create_TTM() for ARPA TLL and TTM packets as well as create_RMC() for GPS RMC packets. Finally, obtained NMEA0183 strings are sent over UDP protocol to a proper ServerUDP_RS application. Each ServerUDP_RS application listens on one IP address and UDP port (which are definable parameters) and forwards received data to a specified RS-232 serial port. In order to handle N+1 position data streams N+1 instances of this application must be run.

Similarly to the main functionality of the generator, the ServerUDP_RS application was developed in the C++ programming language. The communication between the generator and the ServerUDP_RS application over UDP protocol was implemented using standard Linux socket interface (sys/socket.h and netinet/in.h header files) [11]. Forwarding NMEA0183 text strings received in the ServerUDP_RS to a RS-232 port is based on standard Linux tools, which make RS-232 ports available as files (/dev/ttyS0, /dev/ttyS1, …).

Due to space limitations more details about the implementation of the AIS/ARPA/GPS data generator and the ServerUDP_RS application cannot be provided in this paper. More information about the mechanisms used in the developed software can be found in [6].

The proper operation of the AIS/ARPA/GPS data generator and the ServerUDP_RS application were checked using thorough tests. Simulation of object movement was verified by observing visualizations in graphical mode, investigating diagnostic communicates displayed in the text log and analyzing events occurring during simulation using OMNEST Sequence Chart [9]. Generation of AIS/ARPA/GPS position data in NMEA0183 format was additionally tested using available online message decoders [1, 2, 5, 7]. All performed tests confirmed proper operation of the described generator.

APPLICATIONS

The described AIS/ARPA/GPS data generator provides a very extensive set of the input parameters including definable number of simulated tracked ships and PBG tracking ships, which is limited only by memory and processing power of the computer. In the generator two classes of tracked ships with different characteristics such as dimensions, speed, maximum draught and availability of AIS equipment are offered and fully definable. PBG ships have an extended set of characteristics including parameters of ARPA radars and AIS receivers such as range, loss probability and measurements errors (only for ARPA radars). Due to limited space a full description of the generator input variables is not provided in this paper and can be found in [6]. The number of objects which can be simulated in real-time depends on the parameters of the generator and the computer used to run the generator. Using our laptop with Intel Core i7-2670QM 4x2.20GHz CPU and 8GB RAM we were able to simulate up to 10000 objects in real-time with the generator run in text mode.

The AIS/ARPA/GPS data generator has been run using different configuration settings to thoroughly test various functionalities of the software developed under the grant [3]. Using the generator both map and tabular visualization of AIS/ARPA/GPS position data has been validated. Due to the fact that the generator allows simulating a large number of objects on the sea, it will be very useful in performance tests of the mentioned above software, which will be carried out in the near future.

Screenshots from a single test of map and tabular visualization functionality are presented in figures 2–5. Figure 2 presents the generator running in graphical mode, in which the window is split into two parts. At the top visualization of the simulated objects is available, while at the bottom text log with additional information regarding current simulation state is provided. We can see that in the test 9 tracked ships of class 1 (marked as ds1[0]–ds1[8]) and 1 tracked ship of class 2 (marked as ds2[0]) are simulated. It is assumed that all tracked ships have AIS equipment installed and send AIS position data with intervals specified in the AIS standard [12]. These position data are received by a single PBG ship (marked as jp[0]), which has does not have a radar installed. It only receives AIS position information from the tracked ships. In order to visualize objects from the whole simulated part of the Baltic Sea (represented by the blue rectangle in figure 2) the range of the AIS receiver of the PBG ship was set to 500 km and its loss probability was set to 0. The simulated objects move according to the algorithm presented in the previous section. The position of all objects is refreshed periodically.

In the text log of the AIS/ARPA/GPS data generator (figure 2, at the bottom) we can observe a content of AIS position information in the internal generator format (messages are C++ objects). In the example presented in figure 2 an AIS protocol message of type 1 (position report — 'AIS_M1') is received by the PBG ship and forwarded to the global module, which displays its content in a user friendly way (all standardized AIS protocol fields are presented). The message is then transformed to the NMEA0183 format (also presented in figure 2 — the text starting with '!AIVDM') and sent to the ServerUDP_RS application over UDP protocol. In the log of the ServerUDP_RS application (figure 3) it is demonstrated that the same message (message number 2620) is received and forwarded to a defined RS-232 port (here /dev/tyyS0).

The results of visualization of the simulated objects on a digital map and in a table are presented in figures 4 and 5 respectively. In figure 4 visualized objects are represented by pink symbols with unit vectors pointing the direction of object movement. It can be observed that the same set of objects is visualized in figures 2 and 4.

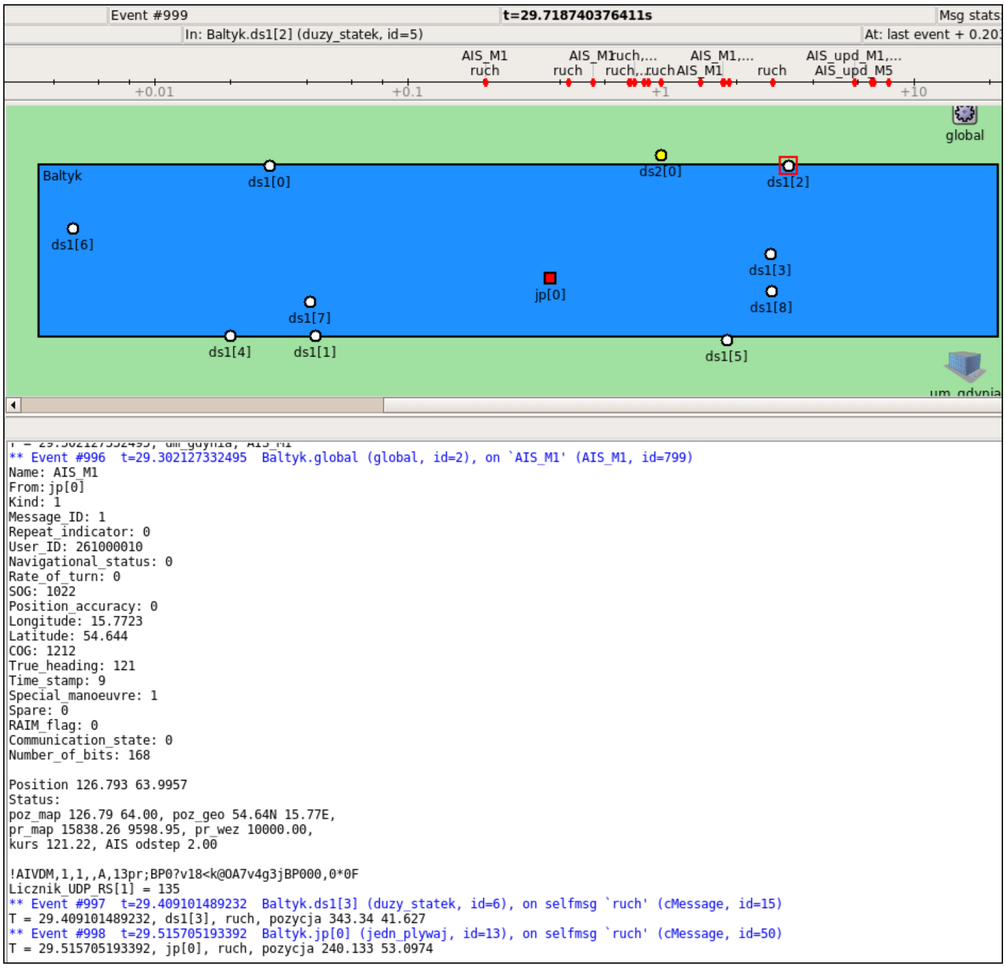


Fig. 2. Fragment of the AIS/ARPA/GPS data generator window (graphical mode)

```
2617
echo '!AIVDM,1,1,,A,13pr;Am00015S:v0;miN4?vBP000,0*7B' > /dev/ttyS0

2618
echo '!AIVDM,1,1,,A,13pr;B@0?vQ0AGPOLMsWOn0BP000,0*08' > /dev/ttyS0

2619
echo '!AIVDM,1,1,,A,13pr;C00?v1CvnvOWs5SWjrBP000,0*6B' > /dev/ttyS0

2620
echo '!AIVDM,1,1,,A,13pr;BP0?v18<k@0A7v4g3jBP000,0*0F' > /dev/ttyS0
```

Fig. 3. Fragment of the ServerUDP_RS application log

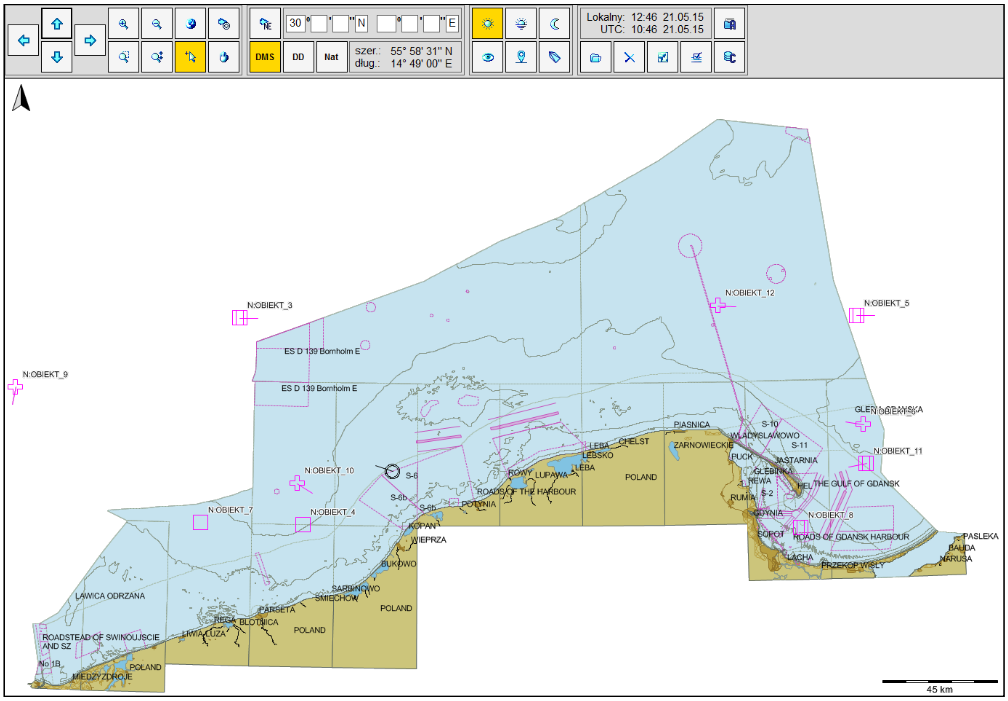
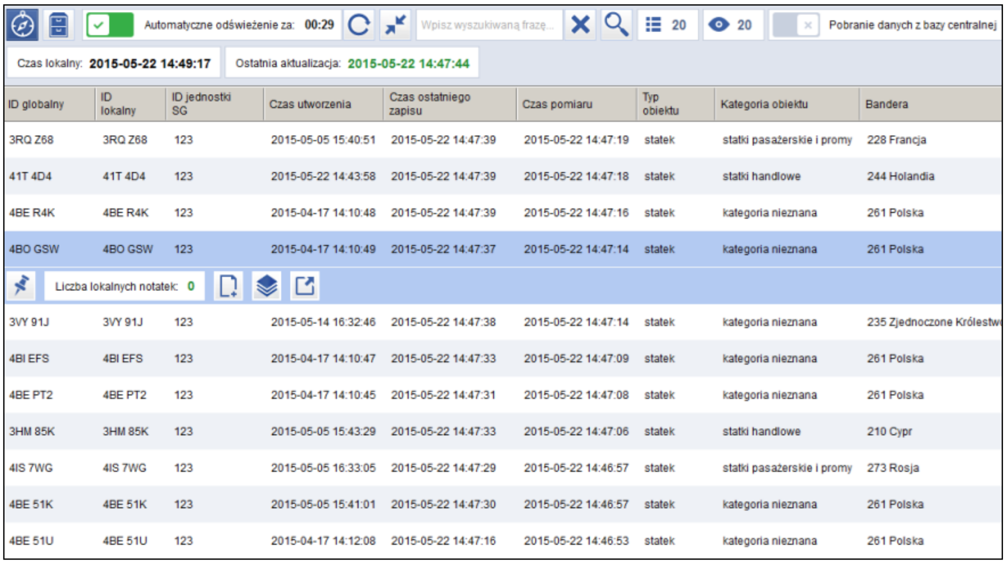


Fig. 4. Visualization of the generated AIS/ARPA/GPS position data on a digital map using 'the console' software [3]



ID globalny	ID lokalny	ID jednostki SG	Czas utworzenia	Czas ostatniego zapisu	Czas pomiaru	Typ obiektu	Kategoria obiektu	Bandera
3RQ Z68	3RQ Z68	123	2015-05-05 15:40:51	2015-05-22 14:47:39	2015-05-22 14:47:19	statek	statki pasażerskie i promy	228 Francja
41T 4D4	41T 4D4	123	2015-05-22 14:43:58	2015-05-22 14:47:39	2015-05-22 14:47:18	statek	statki handlowe	244 Holandia
4BE R4K	4BE R4K	123	2015-04-17 14:10:48	2015-05-22 14:47:39	2015-05-22 14:47:16	statek	kategoria nieznana	261 Polska
4BO GSW	4BO GSW	123	2015-04-17 14:10:49	2015-05-22 14:47:37	2015-05-22 14:47:14	statek	kategoria nieznana	261 Polska
3VY 91J	3VY 91J	123	2015-05-14 16:32:46	2015-05-22 14:47:38	2015-05-22 14:47:14	statek	kategoria nieznana	235 Zjednoczone Królestw
4BI EFS	4BI EFS	123	2015-04-17 14:10:47	2015-05-22 14:47:33	2015-05-22 14:47:09	statek	kategoria nieznana	261 Polska
4BE PT2	4BE PT2	123	2015-04-17 14:10:45	2015-05-22 14:47:31	2015-05-22 14:47:08	statek	kategoria nieznana	261 Polska
3HM 85K	3HM 85K	123	2015-05-05 15:43:29	2015-05-22 14:47:33	2015-05-22 14:47:06	statek	statki handlowe	210 Cypr
4IS 7WG	4IS 7WG	123	2015-05-05 16:33:05	2015-05-22 14:47:29	2015-05-22 14:46:57	statek	statki pasażerskie i promy	273 Rosja
4BE 51K	4BE 51K	123	2015-05-05 15:41:01	2015-05-22 14:47:30	2015-05-22 14:46:57	statek	kategoria nieznana	261 Polska
4BE 51U	4BE 51U	123	2015-04-17 14:12:08	2015-05-22 14:47:16	2015-05-22 14:46:53	statek	kategoria nieznana	261 Polska

Fig. 5. Visualization of the generated AIS/ARPA/GPS position data in a table using 'the console' software [3]

CONCLUSIONS

The paper describes the structure and implementation of the real-time generator of AIS/ARPA/GPS position data, based on the simulation of ships movement on the Polish part of the Baltic Sea. Simulated ships tracked by the PBG sent position information according to the AIS standard. This information is gathered by PBG ships and supplemented by position data from ARPA radars and GPS receivers. All these data are converted to NMEA 0183 text format and generated to defined IP/UDP addresses and RS-232 ports.

The generator supports a very large set of input parameters including definable numbers of particular types of simulated ships limited only by memory and processing power of the computer. Parameters of ARPA radars and AIS receivers such as range, loss probability and measurements errors are also available. Such a number of definable parameters as well as two running modes (graphical mode convenient for debugging and text mode ideal simulating many objects) makes the developed generator a very flexible tool for testing different types of software. One of the applications of the generator are functional tests of the software developed under the grant [3], described very briefly in this paper. The generator is also used in performance tests of the mentioned above software, which are in progress.

Future work with the AIS/ARPA/GPS position data generator will concern implementing the natural coastline and seaports of Poland. This work is not crucial for currently performed tests, however, it is necessary before releasing the generator as a commercial product.

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GENERATOR DANYCH AIS/ARPA/GPS W CZASIE RZECZYWISTYM

STRESZCZENIE

W artykule zaprezentowano generator danych pozycyjnych AIS/ARPA/GPS w czasie rzeczywistym w zestandaryzowanym formacie tekstowym NMEA 0183. Dane pozycyjne są generowane przez zbiór różnorodnych rodzajów statków symulowanych w obrębie polskiej części Morza Bałtyckiego na zadane adresy IP/UDP i porty RS-232. Podczas symulacji uwzględniany jest szeroki zbiór parametrów wejściowych, w tym liczba poszczególnych rodzajów statków, ich rozmiary, prędkość, a także parametry nadajników i odbiorników AIS, radarów ARPA, odbiorników GPS. W artykule opisano architekturę i realizację generatora. Dodatkowo przedstawiono jego zastosowanie do testowania oprogramowania zrealizowanego dla Straży Granicznej.

Słowa kluczowe:

AIS, ARPA, GPS, NMEA 0183, generator w czasie rzeczywistym.