Simulator of Underwater Navigation

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Abstract

Position of surface objects can be fixed in many ways. The most popular radionavigational systems, including satellite systems, make possible obtaining nearly continuous and very precise ship's position. However, under the water application of radionavigational systems is impossible. Underwater navigation requires other tools and solutions then these encountered in surface and air navigation. In underwater environment vehicles and submarines, operate that have to possess alternative navigational systems. Underwater vehicles, in order to perform their tasks require accurate information about their own, current position. At present, they are equipped with inertial navigational systems (INS). Accuracy of INS is very high but in relatively short periods. Position error is directly proportional to time of working of the system. The basic feature of INS is its autonomy and passivity. This characteristic mainly decides that INS is broadly used on submarines and other underwater vehicles. However, due to previously mentioned shortcoming i.e. gradually increasing position error, periodical calibration of the system is necessary. The simplest calibration method is surface or nearly surface application of GPS system. Another solution, which does not require interruption of performed task and emergence on the surface, is application of comparative navigation technique. Information about surrounding environment of the ship, obtained e.g. by means sonic depth finder or board sonar, and comparing it with accessible pattern can be used in order to fix ship's position.

The article presents a structure and a description of working of underwater vehicle navigation system simulator. The simulator works on the basis of comparative navigation methods which exploit in turn digital images of echograms and sonograms. The additional option of the simulator is ability to robust estimation of measurements. One can do it in order to increase accuracy of position fixed with comparative navigation methods application. The simulator can be a basis to build future underwater navigation system.

Keywords: Underwater navigation, comparative navigation.

1. Introduction

The most popular and the most frequently used positioning systems i.e. satellite systems are inaccessible under the surface of the water. For that reason, underwater vehicles and submarines have to possess alternative sources of navigational information.

Small, unmanned underwater vehicles, operating close to mother ships take advantage of hydro acoustic systems. These systems, which we can rate among integrated positioning systems, are advanced software packages, designed specially for integration of USBL (Ultra Short BaseLine) and DGPS. Such system incorporates tracking and navigation of both surface and underwater ships. Consecutive versions of these systems are characterized by different length of base line (distance between transponders). In these systems, vehicle's position is fixed with relation to tracked mother ship. Underwater vehicles besides above-mentioned hydro-acoustic systems are equipped also with inertial systems (INS).

INS are very accurate systems but in short periods of time. They fix position on the basis of data received from gyroscopes and accelerometers. An error of position generated by INS is directly proportional to duration of working of the system. INS requires calibration. The simplest calibration method is surface or near surface GPS application. However, in this situation, the system loses autonomy. Another solution, which does not require interruption of performed task and emergence on the surface, is application of comparative navigation technique. Information about surrounding environment of the ship, obtained e.g. by means sonic depth finder or board sonar, and comparing it with accessible pattern can be used in order to fix ship's position.

2. The conception of underwater navigation simulator

The proposed conception is based on comparative methods and information coming from hydro-acoustic systems application. In the conception, well-known minimal distance methods can be used that compare recorded images (signals) with patterns included in database, or other methods that approximate positions of input images in relation to pattern images can be also applied. The latter methods can work on the basis of artificial neural networks. In the course of these methods studies the computer simulator to carry out navigation of underwater vehicle was created.

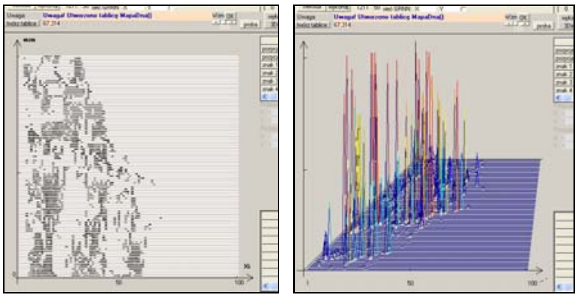
The preparation of input data that constituted a research base was the first stage in creating the simulator. Obtaining or alternatively working out the digital model of the sea bottom, constituting environment in which the vehicle operates was necessary. The next elements that were worked out during preparation of the simulator are: working of sonar systems, echograms and sonograms simulation, storage and data processing.

2.1 Working of sonar systems simulation

Preliminary assumption includes deterministic-random (dual) character of sonar systems parameters. Simulated device should work in water environment of definite geo-physical parameters. Accordingly, the following elements were solved (Felski, Szulc, Waz, 2002):

A1. "Ideal" water environment parameters simulation (depth of the stretch, numerical model of the sea bottom, velocity of sound wave propagation in water, salinity, temperature, a type of bottom etc.);

A2. Disturbed (random) environment parameters generation (normal, uniform distribution; gross errors (single, random); noises correlations etc.);
B1. „Ideal" working of hydro-acoustic devices simulation (signal intensity and power, range, horizontal and vertical beam width, sonar measuring transducers localization to submerge unit diametric line relation etc.);
B2. Generation of noised (random) working parameters of hydro-acoustic devices (low random noise, normal distribution);
C1. Generation of deterministic receiver working parameters (depth finder and sonar probing measurements processing);
C2. Generation of noised receiver working parameters (normal or uniform noise distribution, single gross errors, noises correlations);
D1. Working out of the graphic interface (visualization of systems' work, user's interface, data memorizing etc.).



a) b)

Figure 1. Sonar working visualization canal (window (a)- "classic" sonogram; window (b)- 3D sonogram)

2.2 Simulation of the ship's position fixing system (comparative navigation)

Ship's position fixing system takes advantage of comparative methods applied in maritime navigation. An image obtained as a result of measurement is compared with images memorized in database or with images generated on the basis of known model of the sea bottom. We fix position of underwater vehicle applying to this purpose minimal distance methods or artificial neural networks. Minimal distance methods used in designed simulator fix position of registered image searching for the most similar counterpart among pattern images from database whereas neural networks approximate position of recorded image in relation to positions of pattern images. The simulator exploits the following similarity functions and neural networks:

A. Distance functions: Euclidean distance, Camberra distance;
B. Proximity functions : Tanimoto function;
C. Correlation;
D. Artificial neural networks; GRNN, three-layered perceptron

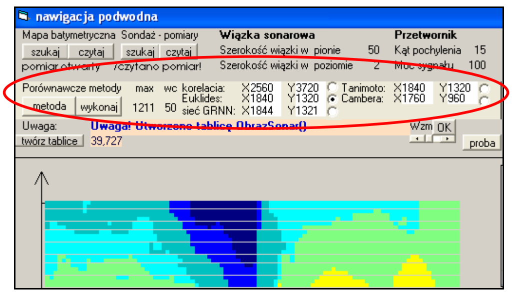


Figure 2. The fragment of "underwater navigation" interface containing information necessary to activate the process of position fixing

The designed simulator is not a complete tool allowing its application in whole process of position fixing of underwater vehicle. It has certain simplifications and limitations resulting from the fact that it was created mainly in order to verify previously made hypothesizes and assumptions concerning possibility of comparative techniques application in underwater vehicles positioning. An important feature of simulator's implementation is its potential to gradual development. It is an open system, which enables addition of next functionalities and options.

3. Working of underwater vehicle navigation simulator

The first user's activity is searching for and reading a file containing a chart of a bottom (A). We can do it by means of standard OpenFile Windows window.
The next activity is a presentation of the bottom chart in 2D format (B) and a determination of geographical coordinates of underwater vehicle starting position (C). We activate vehicle fixing its course and velocity (D).
Movement of the vehicle is dynamical, regardless of remaining simulator elements work. The process that controls the vehicle presents separate thread of the program. Maneuvering is smooth.
A user can adjust characteristics of sonar device work before hydro-acoustic measurements (E). We activate hydro-acoustic measurements by pressing a mouse button in place marked by letter (F). Echogram can be saved and read to program by means of appropriate controls (G). A user can read files with archival data (G1). The next step is fixing position with the application of comparative method. A user runs chosen algorithm (H) and after calculations (It can last few seconds) he can select one of the methods (H1) that results are taken into consideration in the next processes.
Identification and selection of bottom elements takes place by means of mouse in window presenting 2D chart (J). Caution!: maximal number of selected objects amounts to 5. We can choose next objects only after removal from memory recently saved object or all selected objects at the same time (J1). Coordinates of selected bottom objects, values of Brg, Rng and average errors of Brg and Rng can be corrected and altered by a user by means of keyboard. Activation of group of controls is in this situation necessary.
A procedure of measurements results and fixed positions robust estimation takes place by means of two controls (L). They use and run database objects ADO – FlexGrid that constitute spreadsheets.

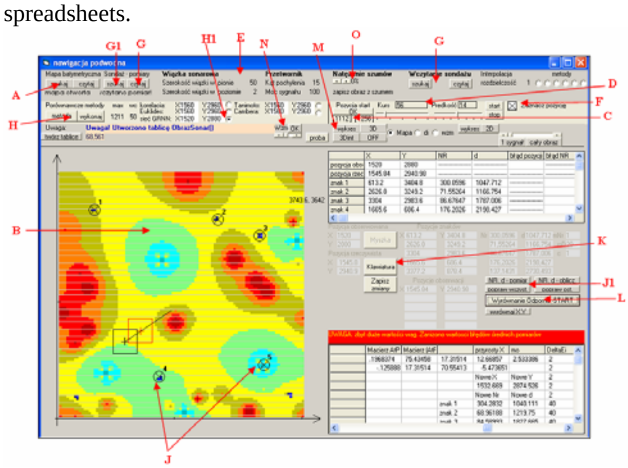


Figure 3. The user's interface of „underwater navigation" program

The presentation of charts, echograms and their 3D representations takes place by means of controls (M). A user can change reinforcement of hydro-acoustic signals returning to sonar (N) and determine value of noises disrupting propagation of sound wave spreading in simulated water environment (O).

4. Experiments

In the first stage of research, we examine correctness of our assumptions concerning building the simulator of sonar devices. Results of these experiments were of great importance in further process of simulator construction.

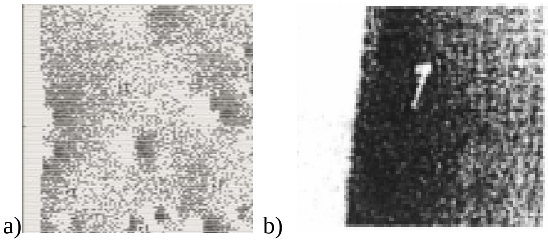


Figure 4. Sonograms: simulated (a) real (b)

All experiments were conducted on different research stretches. Every research stretch was characterized by different shape of a bottom. There were stretches of varied and characteristic bottom but also there were areas, which bottom was more flat. In order to conduct measurements results and calculated position robust estimation characteristic objects were dropped on the bottom. Position of these objects was known for the system's user.

There were conducted several runs over every research area. During this process, bearing and velocity of a vehicle were altered. It is necessary to note that comparative navigation methods accomplish better results when bottom depth gradient is high.

Random noise generator is also the part of designed simulator. Noise of both working parameters of hydro-acoustic devices and parameters of simulated environment is generated by this part of the simulator. A system's user has influence solely on the range of generated noise. Temporary values of noise are not known for system's operator. Thus, measurements and registrations of vehicle devices are always unique. Such approach restricts possibility of occurrence of similar simulated situations.

The following results were accomplished as a result of conducted experiments.

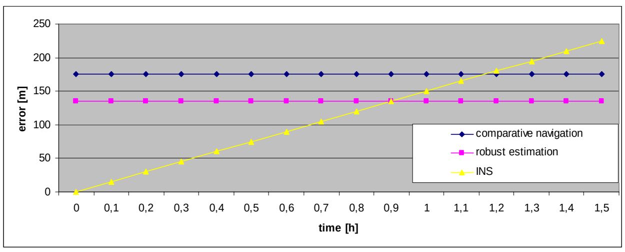


Figure 5. Comparison of average errors of position generated by means of the simulator with errors of INS

An error of underwater vehicle position obtained with the application of comparative methods is independent on working time of the system. The following parameters affect its value: resolution and size of both sonar images and model of the sea bottom, chosen proximity function or approximating neural network. The INS's position error increases over time and after one hour it is higher then error of position generated by the simulator.

5. Conclusions

The designed simulator is not a read solution that could be used in real conditions. Nevertheless, it constitutes a perfect research tool that can expand and develop. At this phase of research, it allows to prove assumed thesis whereas generalized results of conducted simulations let us formulate the first conclusions concerning accuracy of underwater vehicle navigation performed on the basis of the presented system. However, in order to obtain complete information about usefulness of the proposed tool to conduct underwater navigation further experiments are necessary.

Reference

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