Analyzing Efficiency of Using a Set of Metering Equipment to Solve Heading Problems

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Abstract. The purpose of this research work is to conduct experimental research on the accuracy of three types of compass systems: UKPM-M magnetic compass, SSC200 hardbody digital compass, and PGM-C-009 gyrocompass. The study was carried out in Amur Bay. The heading was measured when the study vessel was controlled by the automatic steering device and manually, under no waves, seaways, and free driving. The data obtained were analyzed using spectral analysis. Based on the accuracy measurements, we considered the possibility of using the most accurate data about the heading as the input for the automated vessel steering system.

1. Introduction

Marine heading indication systems are used to determine the course of the vessel. This term stands for various types of compasses: magnetic, digital, satellite, and gyroscopic. Compasses are used to set and keep the vessel’s course, take bearings on lighthouses and other base points, determine off-bow angles, as well as wind and current directions. [5]

Onboard heading indicators (navigation compasses) are the most important navigation devices on marine vessels. The current trends in providing navigation safety require the use of the redundancy principle for the key systems and devices of the ship. Therefore, large-capacity vessels normally have two or three heading indicators that work independently and report to a synchronizer (compass monitor). The owners of conventional vessels may now choose what heading indicator to install in addition to the gyrocompass and magnetic compass that are required currently.

Paper [1] analyzes the quality of operation of marine heading indicators on a refrigerator vessel during a real voyage. Recommendations on their use as primary and secondary devices under various sailing conditions.

Papers [2,3] present a comparative analysis of various heading indicator types to assess their current position on modern vessels, as well as comparison tables with various criteria. Based on these works, we can conclude that gyrocompasses and magnetic card compasses remain the key types of heading indicators. They have to be installed on vessels following the requirements of the International Convention for the Safety of Life at Sea (SOLAS). The vessels are required to have magnetic card compasses installed, and vessels with tonnages of over 500 registered tons are also
required to have gyrocompasses. The use of other types of contemporary heading indicators, such as cardless (digital) magnetic compasses, satellite compasses, and inertia navigation systems is not required. These heading indicators are used as secondary ones.

Paper [4] assesses heading indicator parameters through the recording and processing of their readings using the digital signal processing methods.

The purpose of this article is to assess the operability of heading indicators of various types installed on the Gals research vessel (RV) belonging to the Maritime State University named after admiral G.I. Nevelskoy.

The analysis performed aims to assess the capabilities of some types of heading indicators, their advantages and drawbacks in typical sailing scenarios, and assess the feasibility of their use on marine vessels.

This work aims to solve the problem of designing navigation system architecture and using efficient signal processing methods.

2. Theory
The problems of digital signal processing (DSP) often feature the problems of identification and numerical assessment of temporary trends in processes under investigation. In many cases, these trends determine the development of phenomena. Timely and reliable identification of trends in signals allows for prompt and adequate decision-making, which is especially important in adjusting the navigation system readings.

The known identification methods for signal trends mainly rely on two approaches: filtration and statistical processing. When the filtration method is used, it is necessary to know and set filter parameters (e.g. propagation and cut-off frequency coefficients). The use of statistical methods stipulates a preliminary non-formal identification stage for the trend type and hypothesizing about the trend models. Besides, statistical averaging algorithms (e.g. running average) stipulate the knowledge of the statistical parameters of the signal for the correct selection of the scanning window bandwidth. In any case, the efficient use of these methods requires the availability of apriori data about the signal in question, which is not always possible.

3. Statement of problem
This work suggests analyzing the data obtained in experiments from three devices:
- a UKPM-M magnetic compass;
- an SSC200 solid body digital compass;
- a PGM-C-009 gyrocompass.

Table 1 shows the comparison of the parameters of the devices used. The UKPM-M magnetic compass is used for the ongoing metering and indication of the magnetic heading, as well as metering the bearing and off-bow angle on ships and vessels of various classes, cutters, lifeboats, and yachts. It is considered the primary and steering compass [5].

The PGM-C-009 gyrocompass can be used on any types of vessels. It is characterized by small uptime and high accuracy, and it complies with all of the current requirements of the marine navigation systems market [6].

The SSC200 solid-body digital compass is built on a micromechanical high-speed gyroscope, and it provides accurate and stable readings under dynamically changing conditions, including sharp turns and heavy waves. The SSC200 compass is used as a heading indicator in autopilot systems [7, 8, 9].
| Parameter                  | UKPM-M magnetic card compass | Maretron SSC200 magnetic digital compass | PGM-C-009 gyrocompass (gyroazimuth mode) |
|----------------------------|------------------------------|---------------------------------------|----------------------------------------|
| Static course accuracy     | <1° RMS                      | <±0.2° sec                            | <±0.2° sec                             |
| Dynamic accuracy           | -                            | <±0.6° sec                            | <±0.6° sec                             |
| Power                      | Supplied with repeaters      | Operating voltage - DC 9-16 B         | Mains supply 24 (18 - 36) V           |
|                            | broadcasting the compass     | Maximum current consumption – 0.15 A. | Power consumed:                        |
|                            | indicators to the interfaces| Connected directly to the            | - start mode 50 W                     |
|                            | RS232, RS422 (NMEA 0183,    | mains NMEA 2000/0183                  | - operation mode 25 W                  |
|                            | IEC 1162-1)                 |                                        |                                        |
| Weight, kg                 | 0.198                        |                                       |                                        |

When performing the work, we used theoretical and practical research methods, including mathematical modeling during the analysis of the parameters of DSP algorithms. We also used the key provisions of mathematical statistics, statistical analysis, and experimental data processing.

The experiment was carried out on October 27, 2019, in Amur Bay. It was performed on Gals research vessel and took 5 hours. Gals research vessel is a type KTT-16 ship built in Ustka, the People’s Republic of Poland in 1980. It was used as a tuna fishing boat, then retrofitted in 1988 and signed over to the Far Eastern Higher Marine Engineering School. The specifications of Gals research vessel: length - 15.04 m, width - 4 m, tonnage - 21 t, gross register tonnage - 16 register tons, speed - 8 knots, engine output - 165 hp, 400 mm trunk for hydroacoustic installation, research laboratory size - 9 sq. m.

Equipment: hydraulic steering, autosteering connection capacity through a solenoid valve, steering sensor, forward thruster (4 kW output, 75 kgf draft). Navigation equipment: radar set, GPS-Sonar-Chartplotter, digital magnetic compass, VHF radio communicator.

During the experiment, heading readings were recorded from the three heading indicators mentioned above using a portable computer (laptop) via the RS-422 interface and NMEA-0183 protocol. A special intermediary device was made to synchronize data packages with the readings (Figure 1).

![Figure 1. Data reading chart for the experiment.](image-url)
This device was necessary to de-synchronize the information obtained when using standard USB/RS-422 interface converters that allow for connectivity and recording of packages from navigation devices, due to the specific characteristics of the Windows operating system. This de-synchronization is hard to compensate for during the post-processing due to the lack of time tag in NMEA-0183 messages. To record the readings from the UKPM-M compass that lacks a digital interface, we used a specially made device that transmitted magnetic compass readings remotely. It was based on the RM3100 induction magnetometer by PNY allowing for the identification of compass card position with an error of up to 0.2°. Apart from the heading indicators, we also recorded the data on the heel and trim difference of the ship from the BWT901CL digital inclinometer. For some time, the vessel was controlled by the automated steering system, using the Maretron SSC200 magnetic compass as the heading sensor.

The experimental data graph is shown in Figure 2. The figure details the following data recording intervals: 1) straight course movement using the automated steering system; 2) straight course movement without the automated steering; 3) wave disturbance movement; 4) opposite course movement.

4. Results practical significance, proposals and implementation results, experiment results
Provide the results of the analysis of the data obtained for the first interval (from 0.4 to 95 hours). The value measured graph is shown in Figure 3. The reference device is the PGM-C-009 gyrocompass. For the data provided, we obtained the cross-correlation graphs for magnetic compasses and the gyrocompass (Figure 4), as well as the absolute error graphs for magnetic compasses compared to the reference device (Figure 5).
Figure 4. Cross-correlation graphs for magnetic compasses and the gyrocompass for the period from 0.4 to 0.95 hours.

Figure 5. Magnetic compass error graphs for the period from 0.4 to 0.95 hours.

To analyze the frequency domain, we used the main instrument of the signal processing theory, Fourier's transformation theory. The frequency analysis of heading errors measured by compasses depends on the long-term interferences. We identified magnetic compass error ranges for the values obtained (Figure 6).

Low-frequency errors below $f = 0.02$ Hz represent a phenomenon or indefinite oscillations. This phenomenon is related to Schuler's oscillations for frequency distortions near $f = 0.00124$ Hz shown in Figure 6.

One of the solutions that can suppress low-frequency heading distortions is using digital signal filtration methods [10] and synthesizing bandpass filters with finite impulse response [11].
Figure 6. Magnetic compass error range graphs for the period from 0.4 to 0.95 hours.

Our research shows that the main heading metering errors are not only caused by instability in the vessel movement due to course shifting but also by the steering mode (manual or automated). The results of our research can be used in designing devices used in marine navigation.

5. Conclusion
The accuracy of navigation measurements can be improved by combining the reading from devices of various types. This research work reviewed the accuracy of three different ship compasses. Based on the records made by different devices installed on the research vessel, the authors could study the uncertainty of measurements in terms of both amplitude and frequency. Besides, frequency analysis allows for a better assessment of the impact of heading metering errors on navigation. To minimize the errors of automated steering and prevent wrong decision-making by skippers, it is necessary to perform digital filtering of the low-frequency domain.

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