Acoustic-Hydrophysical Testing of a Shallow Site in Coastal Waters of the Korean Strait

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Abstract—The paper describes the results of testing experiments for solving problems of thermometry and positioning of an autonomous underwater vehicle (AUV) in the Korean Strait in a shallow sea with less than 10 m of water. The studies were conducted on acoustic tracks up to 615 m long, sensed with complex phase-shift keyed signals with a central frequency of 2500 Hz. Under field experiment conditions, it was shown that the resolution of the structure of pulse responses makes it possible to sense temperature changes less than one degree and to secure positioning of the AUV with an accuracy better than 1 m when operating in the near-bottom layer.

Keywords: underwater acoustic positioning, pulse response.

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Active exploration and the use of biological, mineral, and technological resources of inland basins, coastal shelf, bights, gulf, and straits requires the creation of specific systems for controlling robotics and monitoring of sea parameters in the environment of shallow and very shallow seas (less than 10 m of water). A marine station of the Korean–Russian Center of Marine and Information Technologies (MTIT) was opened in September 2010, on Norek Island near the southern coast of the Korean Peninsula. The station was founded by the Institute of Science and Technology (republic of Kwangju, Korea) and the Pacific Oceanological Institute (Vladivostok, Russia). The station was created to conducting experimental research and test technological solutions aimed at developing hydroacoustic engineering tools to explore shallow marine waters. As follows from the bathymetry of the area around the island, there is an aquatic area of several square kilometers with less than 10 m of water that can be used for experimental research (Fig. 1). Under these conditions, a difference in depth exceeding 3 m is possible due to tidal effects. In such difficult environmental conditions for acoustic signal propagation, the testing experiments were performed September 15–19. Their goal was to study specific features of the formation and interaction of hydroacoustic and hydrophysical fields using broadband pseudorandom signals. Sensing the marine environment with such signals makes it possible to obtain a pulse response of the propagation channel with exact time reference of individual pulses and to use it for measuring and monitoring the fields of currents and temperature [1, 2]. The same signals can be used in navigation and communication systems on autonomous underwater vehicles (AUVs) of various purpose. When conducting these studies, we solved the important problem of experimental testing of emitting and receiving systems developed for this area and implemented in the mobile hardware–software system [3, 4].

During the first stage, we studied the pulse response patterns of a waveguide on an arbitrarily selected acoustic track when sensed with complex phase-shift keyed signals at a central frequency of 2500 Hz. We installed emitter no. 1 near the bottom at a depth of 8 m and receiving system no. 1 based on a radiohydroacoustic buoy at a depth of 4 m at a distance of 614.5 m from this emitter (Fig. 1). Complex broadband signals (m-sequences 255 symbols long with four carrier frequency periods per symbol) were emitted every minute for 15 h. Cross-correlation processing of received signals with a replica of the emitted signal allowed us to obtain and analytically process the temporal variability of a pulse response of the waveguide on a long track (Fig. 2a). Up to 12 arrivals of acoustic energy with a varying number of reflections from the bottom and the surface were clearly exhibited in the
pulse responses. The hydrophysical measurements were performed simultaneously with acoustic sensing. Depth profiles of temperature, measured with a CTD probe near the receiving system, and sea level variations of tidal origin (dashed line) are shown in Fig. 2b. The ray paths calculated from hydrological data demonstrated that the first two or three arrivals of acoustic energy correspond to ray paths close to the bottom and devoid of surface reflections. As an example, Fig. 3 shows ray paths propagating near the bottom at almost zero angles (Fig. 3a), and rays with bottom and surface reflections propagating in the entire water thickness (Fig. 3b). Such a structure of the acoustic field allowed us to estimate the variability of the sound speed averaged over the track (temperature) in the bottom layer from the data on the propagation time of the first pulse, because the distance traveled by the pulse is equal to the distance between the emitter and receiver. At the initial stage of measurements until 20:00, the computed sound velocity was 1526 m s\(^{-1}\), but it later increased to 1527 m s\(^{-1}\). The temperature, calculated according to the Del Grosso formula, changes from 23.7 to 24.4°C. One can see good agreement between the results and the outcomes of hydrological measurements despite the fact that the latter were performed at a single site. A minor temperature drop near the bottom at 20:00 is due to the arrival of colder waters with the tide from the deep-water part of the Korean Strait.

In addition, there was an unambiguous dependence of the arrival times of the last pulses on sea level variations owing to high and low tides. High tide took place at 18:00 and 05:00 with a peak of 1.1 m at 18:00. The maximal arrival times were recorded during the same hours. This is attributable to the fact that the travel times of pulses, multiply reflected from the bottom and the surface, are sensitive to changes in depth so that the high and low tide levels can be found from variations in the travel time amplitudes [3].

The possibility and accuracy of solving navigational problem for underwater objects at extremely shallow depths were examined during the second stage of the experiment. For this purpose, emitter 1 was used as a source of navigation signals and emitter no. 2 was additionally deployed 180 m from shore at a depth of 3.5 m (Fig. 1). A hydrophone (receiver no. 2) simulated the receiving system of an AUV; it was submerged to a depth of 5 m from a yacht anchored at a site with 6 m of water (Fig. 1). The solution consisted in determining the coordinates of the receiving system, because the yacht was alternatively displaced by the length of the anchor cable (15 m) due to currents and wind. The yacht’s displacements were also fixed every second by GPS.

By the beginning of the experiment, emitters 1 and 2 were 535 and 331 m from the receiving system, respectively. Both sources minutely emitted signals at a 20 s time gap, the signals being of the same complex shape as those in the first stage of the experiment. The