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Application of a Winch-type Towed Acoustic Sensor to a Wave-powered Unmanned Surface Vehicle

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ABSTRACT

Although many countries have focused on anti-submarine warfare for several decades, underwater submarines can hardly be detected by current assets such as patrol aircraft, surface ships and fixed underwater surveillance systems. Due to the difficult conditions of the oceanic environment and the relative quietness of submarines, existing acoustic surveillance platforms are not able to fully cover their mission areas. To fill in the gaps, a winch-type towed acoustic sensor system was developed and integrated into a wave-powered unmanned surface vehicle by the Korea Institute of Ocean Science and Technology. Sea trial tests were conducted to verify manoeuvering, acoustic signal detection, and communication capabilities. During the manoeuvering test, the wave-powered glider successfully moved along programmed waypoints. Despite towing the acoustic sensor system, only 20 per cent of initial electricity was consumed in 20 days. The acoustic sensor was lowered to depths of 100 m -150 m by the winch system, and received signals from an acoustic simulator lowered to depths of 50 m -100 m by RV Jangmok. The continuously simulated tonal signals as submarine noises that were refracted downward could be clearly received and identified by the hydrophone system, from distances of 2 km - 8 km, while it was being towed silently and deeply. In addition, an optical camera provided high-resolution images of surface vessels, allowing integration with acoustic detection of underwater objects. In conclusion, this new platform using a deeply towed hydrophone system is worthy of consideration as an underwater surveillance asset. Future work is required to strengthen inter-asset communication and obstacle avoidance, and to overcome strong currents to make this technology a reliable part of the underwater surveillance network.

Keywords: Winch-type acoustic sensor; Wave-powered glider; Unmanned surface vehicle

1. INTRODUCTION

Since the appearance of military submarines during the WW I, many countries have made unremitting efforts in the field of anti-submarine warfare[1]. In spite of various attempts, there are many limitations on underwater surveillance, mainly due to the complicated oceanic environment and inherent restrictions of each detection asset[2]. Most sonar systems are operated at specific depths, and hence pinged sound sources may not reliably propagate to their targets. Likewise, reflected or emitted noises from targets may not reach sonar systems, since sound velocity in the ocean changes with depth and acoustic rays continuously refract in new directions[3,4]. Furthermore, modern submarines have been built to operate virtually silently and allow little possibility of detection due to advanced shipbuilding technology. In particular, ship-borne detection systems such as hull-mounted and towed array sonar have difficulty identifying target signals against a background of relatively loud ship noises. Airborne systems such as sonobuoy and dipping sonar have short detection ranges and system durations. Fixed acoustic underwater surveillance systems and harbour underwater surveillance systems cover limited areas and require huge budgets for installation and maintenance.

To overcome these spatial and temporal limitations, there has been increasing use of unmanned autonomous systems. The wave-powered glider is one of the latest examples. It is a hybrid sea-surface vehicle that is comprised of a surface float and a submerged glider attached via a tether to the surface float. It is propelled entirely by mechanical conversion of oceanic wave energy into forward thrust[5], which enables reliable propulsion of long duration. The big advantage is its ability to harvest the energy in waves to provide continuous propulsion[6]. In addition, it utilises solar power for navigation instruments, sensors, and satellite communication, which yields unlimited spatial coverage[7].

In spite of these merits, most acoustic sensors on gliders have been operated only near the ocean surface, as they use a series of wings, located on the sub body 7 m below the surface, topropel the vehicle forward using the vertical motion induced by waves[8]. To cover the subsurface and deeper layers, which are criticalfor underwater surveillance, a winch-type towed acoustic sensor system was developed for the first time and sea trial tests were conducted by the Korea Institute of Ocean Science and Technology (KIOST), in the East Sea of Korea in June 2015. This study provides a design overview of the new platform, and presents results from the test deployment, demonstrating its applicability to practical underwater surveillance.

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2. DESIGN OF PLATFORM AND SENSOR

The wave-powered glider is composed of two parts: a surface float that is roughly the size and shape of a surfboard and stays at the surface, and a submersible glider with wings hanging 7 m below the float on an umbilical cable (Fig. 1). An iridium satellite system is used for command, control and data sharing, with GPS satellite transmission used for positioning.

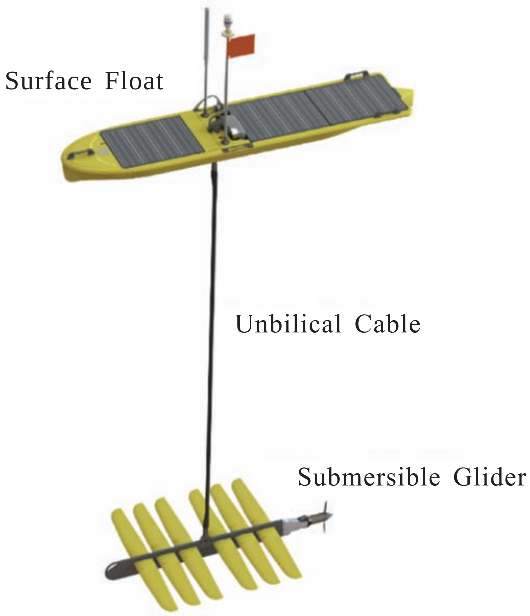

Figure 1. Wave-powered glider (modified from liquid robotics Inc.).

The weather sensors (Airmar Weather Station 200WX) on the surface float measure wind speed and direction, as well as air temperature and pressure. In addition, wave height and direction data are collected by a wave sensor (Datawell Mose-G1000).

For acoustic surveillance, KIOST has developed a winch-type towed acoustic sensor system equipped with a control box, motorised winch and towed hydrophone (Fig. 2). The 13.8-kg control box can save up to 13 days of acoustic raw data, operate the winch, and forward the collected data to the surface float. The winch system is capable of winding and unwinding the 300-m fiber-optic cable at a rate of 4.8 cm/s for the towed hydrophone system.

The towed hydrophone weighs 6.6 kg and is able to operate under 0 psi - 1,000 psi with a sampling rate of 6,144 Hz. This towed hydrophone system is also fitted with water temperature, geomagnetic, and pressure sensors.

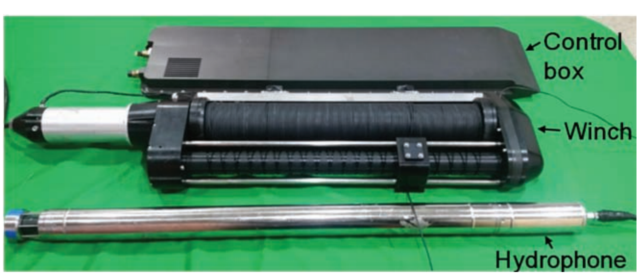

Figure 2. Control box and winch for the 300-m fiber-optic cable.

3. SEA TRIAL RESULTS

The wave-powered unmanned surface vehicle equipped with a winch-type towed acoustic sensor was deployed in the East Sea of Korea by RV Jangmok in June 2015. To test this vehicle's applicability as an underwater surveillance platform, an acoustic signal maker, SeaNos (Fig. 3), which can produce artificial signals at 0.1 kHz - 2 kHz, was used to simulate the noise of a typical submarine.

Figure 3. Underwater acoustic signal maker, SeaNos, manufactured by KIOST.

The sea trial focused on testing manoeuverability, acoustic signal detection, and communication capabilities. During the manoeuvering test, the glider successfully moved along designated way points while towing the acoustic sensor system at variable speeds of 0.2 knots - 2.3 knots (mean = 1.5 knots), consuming only 20 per cent of the initial electricity over 20 days. To test acoustic signal detection, the SeaNos acoustic signal maker was lowered to depths of 50 m - 100 m by RV Jangmok to simulate underwater submarine noises (400 kHz and 700 kHz frequency, 135 dB - 140 dB source level). Under conditions of downward acoustic refraction, the continuously simulated tornal signals were received at distances of 2 km-8 km by the hydrophone, which was lowered to depths of 100 m-150 m by the winch system onboard the submersible glider. Graphs of frequency versus relative intensity show that tonal signals of 450 Hz and 750 Hz are identified from ambient noise (Figs. 4(a), 4(b)), and low frequency analysis and recording (LOFAR) provides clearer identification (Figs. 4(c), 4(d)).

The iridium satellite communication system secured stable command and control and data transmission during the entire sea trial. The infrared-red and optic cameras provided high-resolution images of surface vessels (Fig. 5), which can be integrated with data from acoustically detected underwater objects.

4. CONCLUSION

This sea trial was mainly designed to verify the operability of the winch-type towed acoustic sensor, which was applied to a wave-powered unmanned surface vehicle for the first time by KIOST to investigate its use as an underwater surveillance asset. Through the sea trial, we recognised that the deeply-lowered hydrophone system could receive downwardly refracted target signals, which is the normal refraction condition in the ocean. It was shown that the wave-powered autonomous vehicle could tow the winch-type hydrophone system without making any other mechanical noise or significant reduction in speed. Due to their quietness and small cross section, the surface float, submersible glider, and deep-towed hydrophone have a low possibility of detection by passive and active sonar systems onboard opposing submarines. It appears that, with reliable

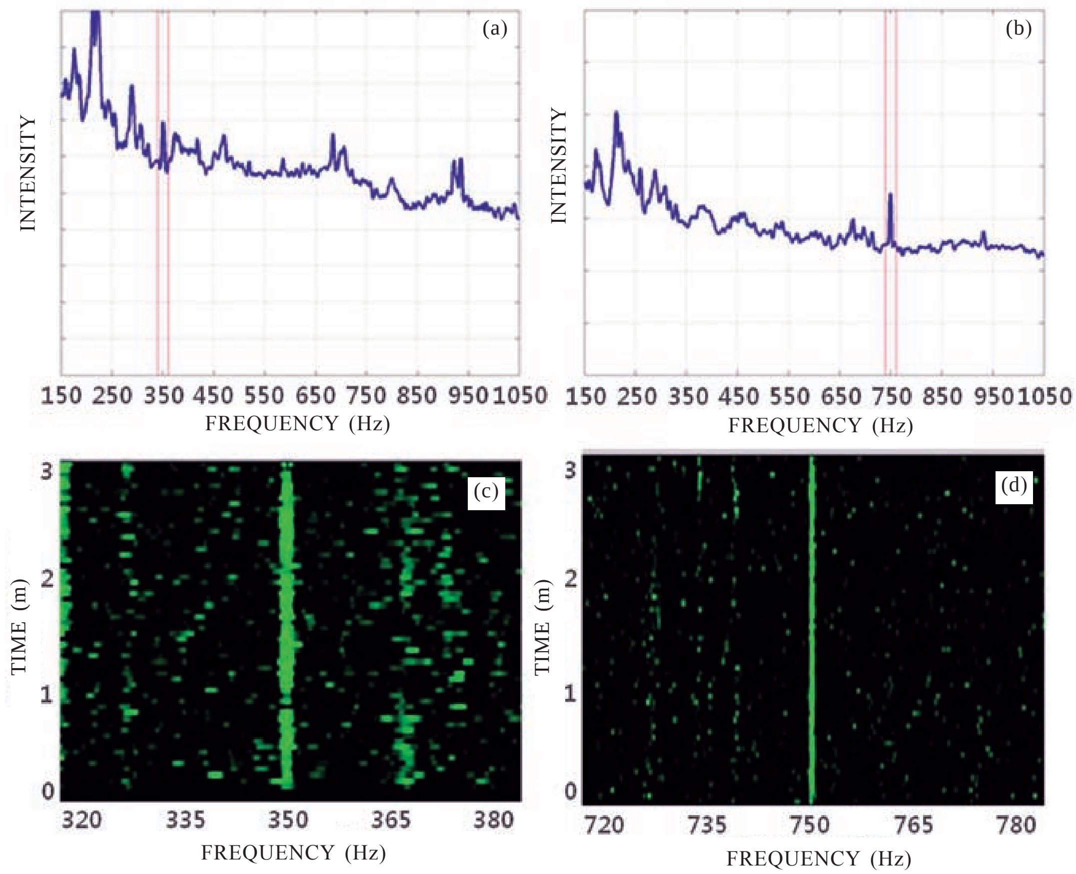

Figure 4. Graphs of frequency *vs* relative intensity (a), (b), and LOFARgrams (c), (d).
Note : Absolute value of signal intensity was not measured due to technical problem.

Figure 5. Image of sea surface and research vessel taken by the optical camera installed on the surface float.

satellite communication and supplementary image cameras, this new platform is worthy of deployment as an underwater surveillance asset.

Future work will be required to strengthen inter-asset communication and obstacle avoidance, and to overcome strong currents to make this vehicle a reliable part of the underwater surveillance network (Fig. 6).

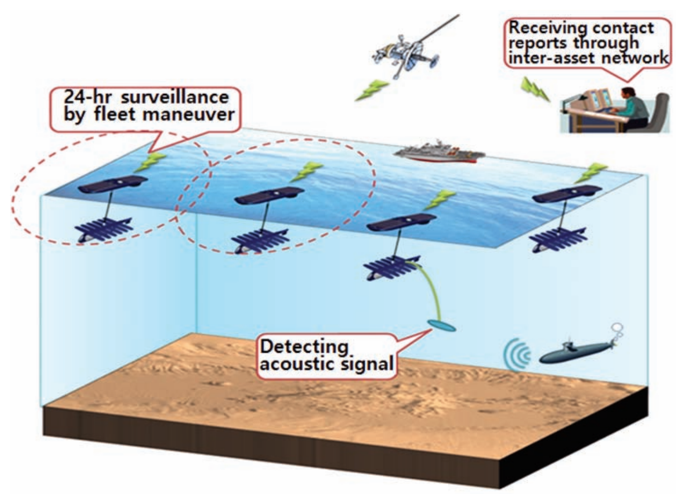

Figure 6. Schematic of an underwater surveillance network made up of multiple wave-powered unmanned surface vehicles.

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CONTRIBUTORS

Mr Taejun Moh received his master's in Ocean Engineering at Stevens Institute of Technology. Presently working as a Defense Research Planning Scientist for the Maritime Security Research Center of KIOST. He has 20 years of experience in anti-submarine warfare and battle space intelligence as a naval officer in Korea. He has led multiple team projects in the field of underwater surveillance networks.
In the present work, he has designed the integration of wave-powered unmanned surface vehicle and winch-type towed acoustic sensor.

Mr Namdo Jang is the Supervisory Marine Engineer for Maritime Security Research Center of KIOST. In his role, he has managed the Autonomous System Team and coordinated various programs for operational research and development.
In the present work, he has technically managed the entire procedure for the application of the winch-type towed acoustic sensor to wave-powered unmanned surface vehicle.

Mr Seok Jang is the Chief Marine Engineer for the Maritime Security Research Center of KIOST, where he has more than 23 years of experience in operational oceanographic surveys and development of autonomous systems. He has participated in many naval projects to develop anti-submarine warfare capabilities.
In the current study, he has contributed in planning the sea trial and leading technical assistance.

Dr Jin Hyung Cho received his PhD from Chungnam National University. Currently working as Research Scientist for the Maritime Security Research Center of KIOST. He has 17 years of experience in environmental oceanography and unmanned autonomous vehicle. He has led various projects in the field of naval operational oceanography.
In the present work, he has conducted data analysis and wrote the manuscript.