Development of the Sledge-Type Underwater Metal Detection System for Underwater Cultural Heritage Exploration

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Abstract

The National Research Institute of Maritime Cultural Heritage (NRIMCH) in Republic of Korea has promoted the 4-years 'Development Project of Underwater Cultural Heritage Exploration Techniques' from 2013 through 2016. During the project, the metallic cultural heritage made of bronze could not be detected with the magnetometer, but NRIMCH has developed the sledge-type underwater metal detection system suitable for exploring metallic material underwater cultural heritage including bronze.

A magnetometer or metal detectors are used to detect metallic objects exposed or buried in the seabed. In case of magnetometer, the depth of exploration is deep and exploration work is fast, but there is a disadvantage that non-ferrous metals except iron is not reacted. When using a metal detector, which is a type of electromagnetic exploration, there is a method using a portable metal detector and a method of towing an antenna in a vessel. In the case of a portable metal detector, since the diver is directly using it underwater, there is a time limitation and a disadvantage that it is difficult to know the position. In addition, when the antenna is towed at the vessel, the antenna is spaced at a considerable distance from the seabed, so that the buried metal cultural heritage may not be detected. To overcome these drawbacks, this system aims to develop an antenna platform as a method for bringing the antenna of the metal detector closer to the seabed. The antenna platform is made of metal-free PVC and designed as a caterpillar. The caterpillar shape allows easy passage of obstacles in the sea floor and allows the antenna to be wrapped and protected. In addition, software was developed to verify and store location information obtained using DGPS and response values for underwater metal cultural heritage obtained through the antenna platform in real time.

Key words: UCH, Korea, magnetometer, survey

Introduction

Since ancient times, Korea has been active in trade, reverence, and cultural exchanges with neighboring countries; and there are many naval battles from the Joseon Dynasty to the modern times, so it is very likely that various artifacts are buried in the seabed. The artifacts that are buried in seabed are mainly porcelain, metallic artifacts, wooden artifacts, and life products on ships. It is important to find artifacts because buried artifacts are important as historical facts and evidence.

Many studies have been conducted to find metal objects buried in underwater through physical exploration techniques. In Korea, Jung Hyun-Ki and others studied the electric and magnetic exploration used for underwater burial objects investigations (Jung Hyun-Ki et al., 2004), Park In-Seok and others studied the magnetic exploration method for underwater artifacts (Park In-Seok et al., 2013). E. Weiss and others developed a system using magnetic exploration to detect and to accurately map metal objects buried beneath the shallow waters (Weiss et al., 2007). S. Tripati and others studied the material of a shipwreck through an underwater metal detector and an antenna dipstick metal detector (Tripati et al., 2004). As a result of these studies, the physical exploration technique to find metal objects buried in seabed using magnetic exploration or electromagnetic exploration has been developed. In the case of magnetic exploration, it is the most effective method of exploration for artifacts made of iron, but it does not respond to metals such as gold, silver, and copper. There are two methods of electromagnetic surveying using the metal detector; one is submerging and diving with the equipment, and the other is towing the antenna in underwater. The method of submerging and exploring divers with equipment is time consuming and has a disadvantage; it cannot precisely locate the position. And the disadvantages of the latter are that If the antenna is located at a considerable distance from the sea floor, it may not detect buried metal artifacts.

To solve these problems, the authors developed the sledge-type underwater metal detection system that can be operated close to the sea floor to compensate for the disadvantages of magnetic and electromagnetic exploration. In addition, the performance of the metal detection system using the antenna platform was verified after the iron pot and the bronze canon were buried in the sea floor, 1m and 2m of the seabed in Geoje sea area, Taean sea area, and Nakdong river area.

Method and Principle of Metal Detection

In the physical exploration technique, metal detection methods include a magnetic exploration to detect magnetic metallic materials, and an electromagnetic exploration to detect non-magnetic metallic objects such as gold, silver, and copper. Magnetic exploration is used to identify the geological structure of the geomagnetic field or its components generated by fluid motion in the outer core of the earth; and this technique is used for ground survey, soil exploration, and resource exploration. And a secondary electric field is generated due to the induction current flowing in the underground conductive body by the primary electric field. By detecting the characteristics of this secondary field, information on the location and shape of metal in the underground can be obtained.

Configuration of the Sledge-Type Underwater Metal Detection System

As shown in Fig. 1, the sledge-type metal detection system consists of a metal detector, DGPS, and an antenna platform for bringing the antenna into close contact with the sea floor. It includes software to monitor and store the positional information collected from DGPS and reaction values received from metal detector in real time on PC.

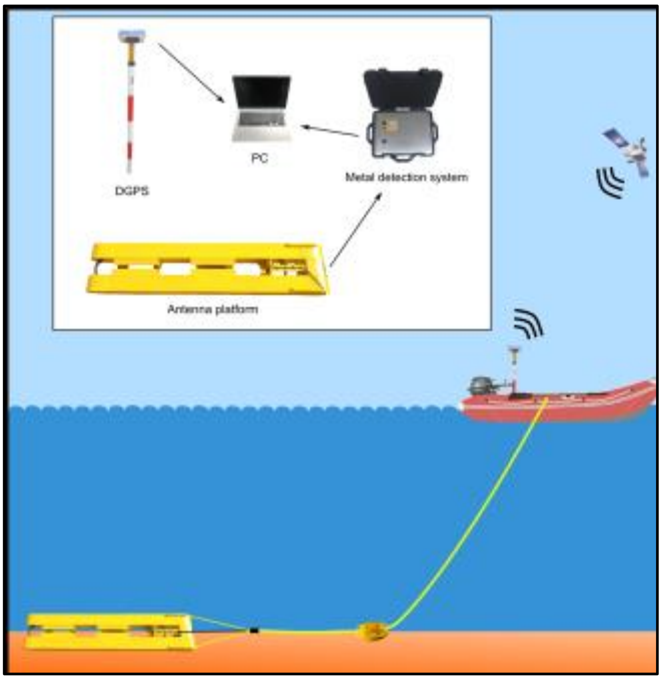

Fig. 1(left): Schematic Diagram.

1. Metal detector

The metal detector used in this study is a method of detecting metal objects by using time difference of transmission and reception by pulse induction method.

Since the time of transmission and reception is different, it is possible to detect metal objects by using one antenna, and it can be used in seawater because it is not affected by medium between metal detector and metal objects. The original metal detector informs the metal response by sound through the instrument cluster and headset. We use DAQ (Data Acquisition) to convert analog signals such as instrument panel and sound into digital signals and to enable real-time monitoring and storage on the PC through software. In addition, it was supplemented with a buzzer so that the change of the reaction value can be immediately recognized (Fig. 2).

Fig. 2: Metal Detector.

2. DGPS

DGPS was used to identify the wake of the exploration vessel. The DGPS uses two or more GPS receivers to reduce positional errors. The location information comes in the form of NMEA0183, which shows the wake of the exploration vessel through the software.

3. Sledge-type antenna platform

The size of the antenna is 20cm x 110cm. A cable (about 30m long) is attached to the antenna. The resistance of the antenna is 1.75O and the inductance is 189μH. The antenna platform uses PVC which does not contain metal material. As shown in Fig. 3, the antenna platform is manufactured in a caterpillar shape so that it can be closely contacted to the sea floor. It is designed to overcome obstacles and protects the antenna. The rope was connected to both ends of the antenna platform, and the rope was knotted above the center of gravity to form a ring, and then a descending line was placed to secure land on the undersurface. In addition, it is possible to create a space in which an underwater camera can be placed at a position that does not affect the antenna, so that the sea floor can be confirmed as an image. In addition, a weight was produced to prevent the buoyancy caused by the cable during the survey.

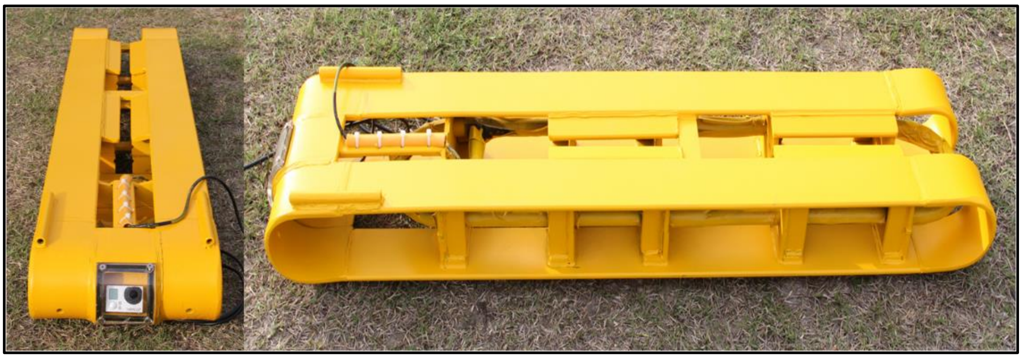

Fig. 3: Platform.

4. Software

It is possible to monitor and record the incoming signal from the metal detector and the DGPS location information on the PC in real time. The software was built using Mathworks' MATLAB GUI. The software installs a driver for National Instruments USB-6000, a data acquisition device connected to a metal detector, to receive data from MATLAB. The locational information of DGPS is output in the form of NMEA0183, and it is indicated by the latitude and the longitude through parsing. The software records the data in real time, ensuring that material acquired in a sudden emergency is protected. Also, there is a start button with or without DGPS for single use without DGPS.

Acquisition and Processing Data

1. Field experiment

The experimental research was conducted in 3 sites: Taean sea area, Geoje sea area, and Nakdong river area. In the Taean and Geoje sea areas, the size of the research area were 100m × 100m; and the size of the research area in the Nakdong river was 50m × 200m. Iron pots, ceramics and bronze cannons were used as experimental samples. They were intentional buried at 1m, 2m deep under the seabed and sea floor. A rubber boat was used to minimize the electromagnetic noise in the acquisition of data, and its operation speed of the exploration vessel was below 4km/h. The exploration vessels operated in the 'east-west direction' and the 'north-south direction' in the research areas.

2. Data processing

Two kinds of processing were performed to process the data obtained from field experiments. The DGPS was installed on the exploration vessel and collected data of the antenna platform and position. Then, the raw data coming from the metal detector shows DC deflection, which uses a high-pass filter to remove the DC deflection.

3. Layback calibration

For layback calibration, the depth of the area where the survey is performed was required; and the length of the cable to lower the antenna platform was also required. For example, if one of the field test sites is 3m in depth with a 23m in cable length, the horizontal distance between the exploration vessel and the antenna platform is 22.5m.

4. DC deflection removal

When data coming directly from the metal detector, DC deflection appeared in some sections and it can be removed through a high-pass filter. A high-pass filter is a filter that removes less than the specified cut-off frequency and passes the higher frequency band. In this study, a cut-off frequency of 0.1Hz was specified and the higher values were separated by passing only the higher frequency components.

Results

Taean sea area

Fig. 4 is the profile of the electromotive force value obtained from the Taean sea area. (a) It is the survey line that goes through east-west upon 1 iron pot, 1 bronze cannon buried at 1m, and 2 iron pots, 2 bronze cannons buried at 1m. The electromotive force value is measured higher in the region of double numbered experimental sample areas. (b) It is the survey line that goes through east-west to 1 iron pot, 1 bronze cannon buried at 2m, and 1 iron pot, 1 bronze cannon on bottom. It shows that the electromotive force value is high near the iron pot, bronze cannon. (c) It is the survey line that goes through south-north to 3 iron pots, 1 bronze cannon buried at 1m, and 3 iron pots, 1 bronze cannon buried at 2m. Through the profile analysis, we could distinguish 3 iron pots buried at 2m which did not appear in electromotive force abnormality. (d) It is the survey line that goes through south-north upon 6 iron pots buried at 1m, and 3 iron pots, 1 bronze cannon on the bottom. The electromotive force value was the highest in 3 iron pots on the bottom; and 6 iron pots buried at 1m showed higher electromotive force than 1 bronze cannon on the bottom.

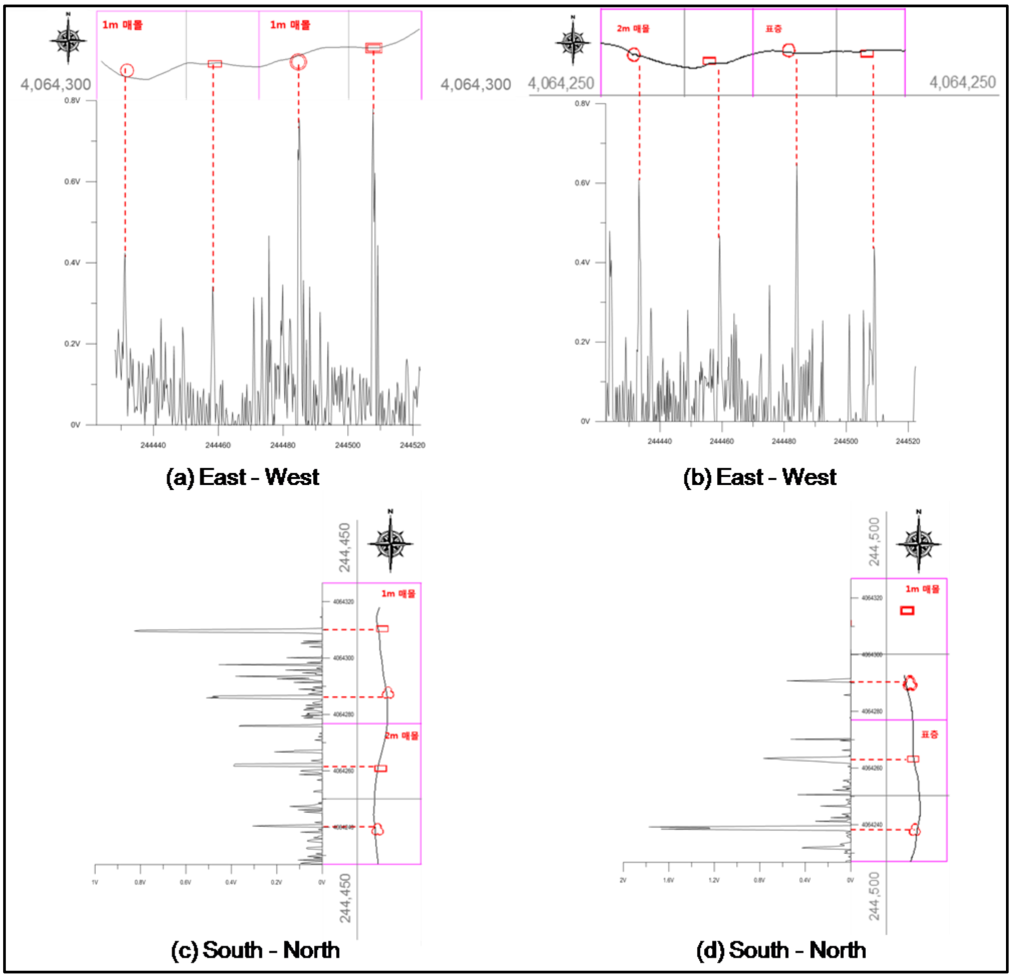

Fig. 4: Taean Results.

Geoje sea area

Fig. 5 is the profile of the electromotive force value obtained from the Geoje sea area. (a) It is the survey line that goes through east-west upon 1 iron pot, 1 bronze cannon, 2 iron pots, 2 bronze cannons buried at 1m. The electromotive force values in this region are high around the experimental sample. (b) It is the survey line that goes through east-west upon 1 iron pot, 1 bronze cannon buried at 2m, and 1 iron pot on the bottom. A signal that was observed between the iron pot and the bronze cannon buried at 2m was not the experimental sample, and the value of the electromotive force value was measured high near the pot and the bronze cannon. (c) It is the survey line that goes through south-north upon 6 iron pots, 2 bronze cannons buried at 1m, and 3 iron pots, 1 bronze cannon on the bottom. It shows the largest electromotive force value at 3 pots on the bottom, and it has large values mainly around the experimental sample. (d) It is the survey line that goes through south-north upon 1 iron pot buried at 1m, and 1 iron pot buried at 2m. Based on the electromotive force value, anomalous signal in the marked area are detected nearby metal objects.

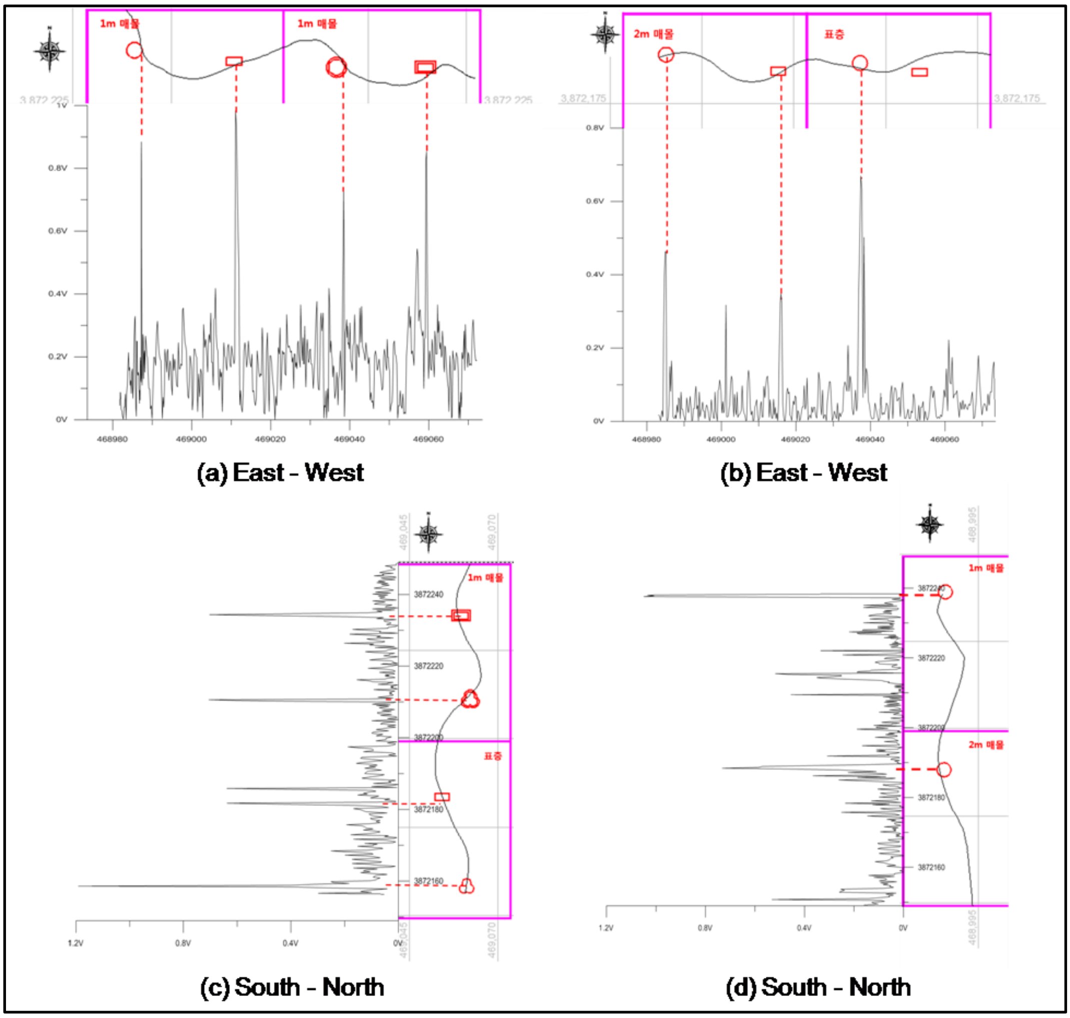

Fig. 5: Geoje Results.

Nakdong river area

Fig. 6 is the profile of the electromotive force value obtained from the Nakdong river area water bottom. (a) It is the survey line that goes through east-west upon 3 iron pots, 6 iron pots buried at 1m, 3 iron pots buried at 2m, and 1 iron pot on the bottom. At the place that 1 pot buried at 1m, the electromotive force value is 1.0V; and one that 1 pot buried at 2m, it has 0.8V. And when the antenna passes near the iron pot on the bottom, the electromotive force value measured by the metal detector is as high as about 2.3V. (b) It is the survey line that goes through east-west upon 1 iron pot, 1 bronze cannon, 2 iron pots, 2 bronze cannons buried at 1m, and 1 iron pot, 1 bronze cannon buried at 2m, and 3 iron pots, 1 bronze cannon on the bottom. The position is greatly deviated from the 2 pots buried at 1m. The electromotive force value of this time was not the iron pot but the value of other objects on the bottom, or it appears as a layback error due to water depth or obstacle on the bottom. Overall, we can see that there is less noise than in other areas.

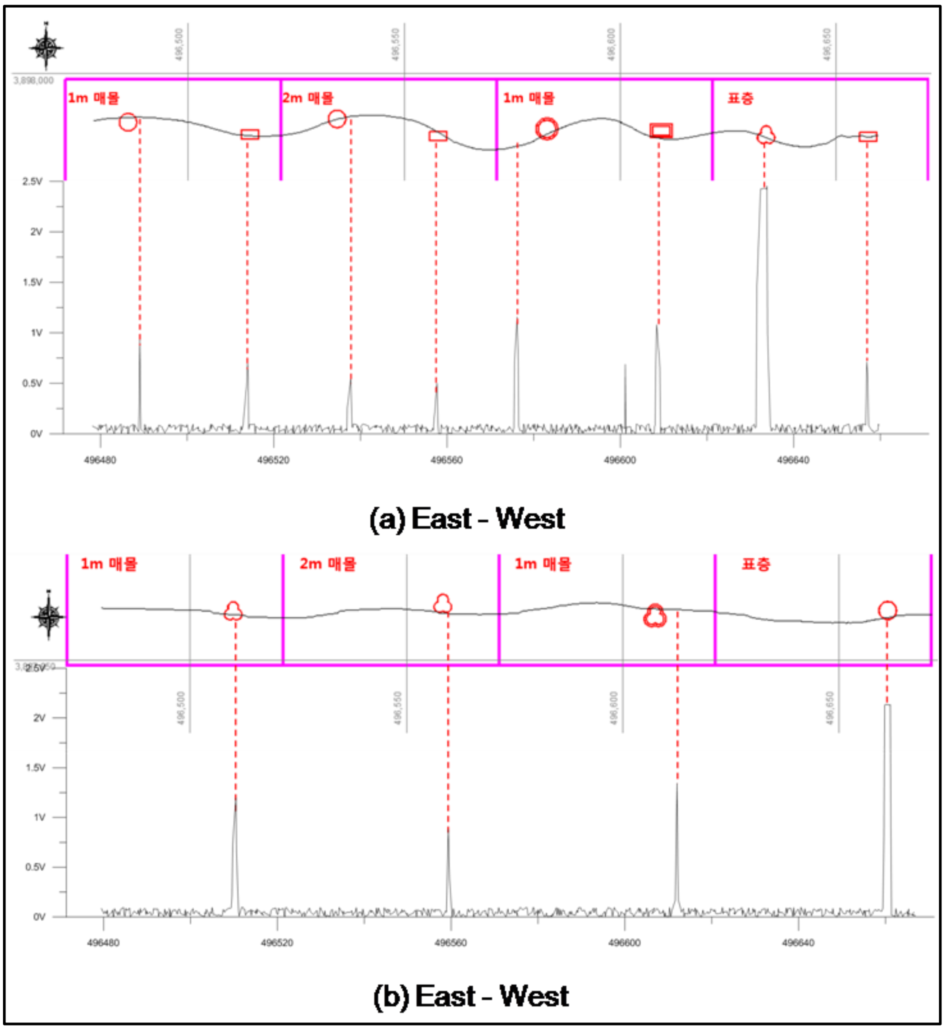

Fig. 6: Nakdong River Results.

Conclusion

Most of the underwater cultural heritage in Korea are accidentally discovered during fishing activities; a systematic exploration of the regionhas not been done yet. The operation of metal detectors is necessary to find non-ferrous metals such as gold, silver, copper, and bronze, but the present operating method has many drawbacks. In this study, the sledge-type underwater metal detection system was developed and applied to the field to overcome these disadvantages. Then, the following results were obtained.

First of all, it can identify iron pots and bronze cannons buried in various depths and numbers. Secondly, it can possibly identify bronze cannons;

this was impossible to be identified by conventional magnetic exploration. Thirdly, there is less noise in the Nakdong river area than in the Taean and Geoje sea areas. Unlike the Taean and Geoje sea areas, the Nakdong river area does not have any fishery activity/industry; consequently, this result might be caused by lack of iron abnormalities such as trapping on the bottom. Fourthly, there was a section where the metal reaction/position differed from the actual position of the buried experiment sample. This might be caused by the position error of the DGPS and the error of the layback correction. In conclusion, based on these results, the sledge-type underwater metal detection system will contribute to the discovery and protection of underwater cultural heritage if applied to underwater cultural heritage exploration.

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Biographies

Yong-Hwa Jung is a Researcher & Conservator in the Underwater Excavation & Conservation Division of the National Research Institute of Maritime Cultural Heritage of South Korea. He earned his PhD in 2008 from Kongju National University. He has been involved in several maritime research projects including: Exploration Project of Underwater Cultural Heritage by the EOS3D-A (3D Seismic Survey System), Development Project of Underwater Cultural Heritage Research Technology Using Crabster CR200, Development Project of Underwater Cultural Heritage Exploration Techniques, Underwater Archaeology Vessel 'NURIAN(G/T 290ton)' Ship building, Underwater Cultural Heritage Preservation Policy in Korea, Analysis of Manufacturing Technology and Production Area of Underwater Excavations Pottery.

Young-Hyun Lee majored the marine geophysical exploration at Dong-A University. He has been working in division of underwater excavation and conservation at the National Research Institute of Maritime Cultural Heritage for 5 years. He had mainly participated in a research project, which is named "Development Project of Underwater Cultural Heritage Exploration Techniques". This project had been conducted by our division from 2013 to 2016. As a marine geophysical researcher, He is still doing my best to apply those developed exploration techniques, which are including utilization methods of equipment and development of equipment, into the underwater archaeology filed.

Jin-Hoo Kim is Professor in Geophysical Engineering. Born in 1955, Seoul, Korea. B.S. from Seoul National University, Korea in 1978. Ph.D. in Geophysics from Colorado School of Mines, U. S. A. in 1986. Currently, he is the department head of Energy and Mineral Resources Engineering Department, and the director of Ocean Resources Research Institute, Dong-A University, Busan, Korea. He has participated in various geophysical exploration projects for in-land and off-shore site investigations, maritime archaeological surveys, and soil and petrophysical researches.

Sang-Hee Lee was born in 1989, Busan, Korea. He graduated from Dong-A University with a bachelor and master degree in Energy and Mineral Resources Engineering. Current, he is studying at Dong-A University to get his doctor's degree. He has participated in geophysical exploration projects for in-land off-shore site investigations, maritime archaeological surveys, petrophysical researches.

Hyun-Do Kim is a CEO at GeoView Co. Ltd., Republic of Korea since 2005, where he has been dealing with marine seismic and geophysical surveying business. He obtained Ph.D. in geophysical survey from department of ocean engineering, Dong-A University, Busan, Republic of Korea, in 2005. Dr. Kim's research interests include marine geophysics and geotechnical survey in in-shore and off-shore. Recently, 3D seismic survey system has been developed and applied to underwater archaeology.

Yeong-Hyun Kim was born in 1979, Busan, Korea. He graduated from Dong-A University, Department of Civil Engineering. He studied river port engineering in Dong-A Graduate School. Currently, He is working at Geoview Corporation, a marine survey company and has been working for 8 years. He is a team leader of marine Survey department. He is charge of marine geophysical surveys and geotechnical surveys.