

Joint airborne and shipborne geophysical surveys to inspect the submerged archaeological sites: The Taijiang Waters in Taiwan

Liwen Chen¹, Sheng-Chong Lo², Lun-Tao Tong³, Gwo-Shyh Song⁴, Yi-Wei Lu²,
Cheng-Wei Tseng³, Jheng-Kai Huang⁵, Wai-lam Wong¹, Wei-Chung Han⁶

1. National Academy of Marine Research, Ocean Affairs Council, Taiwan
2. Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Taiwan
3. Material and Chemical Research Laboratories, Industrial Technology Research Institute, Taiwan
4. MMA Global Aqua Co., Ltd., Taiwan
5. Chinese Ocean & Underwater Technology Association, Taiwan
6. Exploration and Development Research Institute, CPC Corporation, Taiwan

ABSTRACT

To better identify submerged archaeological targets, multiple state-of-art survey techniques were carried out in underwater geoarchaeological studies at the exploration stage. Previous underwater surveys identified ten Dutch colonial vessels dating from the first half of the seventeenth century. Four of them were found on the banks of the Yanshui River, and most of them were situated at the historical waters of Dayun Port. Underwater archeology research at this inland sea of Tainan, the base for the Dutch route, was the key era in the development of maritime trade in Southeast Asia. Therefore, inspecting the potential archaeology in Taijiang Waters is under our consideration, which is situated in a historical city, Tainan, leads us to link the ancient shipwreck event to consider the sustainable preservation solution.

However, it is challenging to inspect the submerged archaeological targets since the geomorphology rapidly changed due to the long- and short-term geological processes. The resources available to conduct the work include accurate frequency control on magnetic data acquisition and comprehensive geophysical integration for data interpretation. Therefore, we combine the acoustic and magnetic techniques and joint airborne and shipborne geophysical surveys to inspect the submerged assessment. After integrating with previous survey results, seven underwater cultural heritages were linked to shipwrecks, which allows us to embark on follow-up verification plans for archaeological research, preserving the potential historical footprints of Taiwanese and the treasure wetlands environments of the Taijiang National Park for endangered ecosystems.

Keywords: geophysical survey, Taijiang Waters, underwater cultural heritage

INTRODUCTION

The topic of this paper fits best within this Session 24 “Database, monitoring, non-intrusive documentation techniques and new technologies applied to underwater cultural heritage” because we jointly apply multiple the-state-of-art survey techniques including airborne- and shipborne-based geophysical methods to inspect the submerged archaeological sites in the Taijiang Waters of Taiwan. Overall, this study is based on non-intrusive geophysical methods and it involves database building and future underwater cultural heritage (UCH) monitoring/preservation.

The Taijiang Waters are archaeologically significant since it was a crucial ship channel during the seventeenth century and therefore many ships sank in its surrounding waters during the period. Previous studies have found at least ten Dutch vessels in the study area dating from the first half of the seventeenth century (Chiang, 1999; Li, 2018; Wang, 2012). However, it is challenging to inspect the submerged archaeological targets by using traditional surveying methods due to the poor visibility in the water, strong tidal currents, and rapidly changing morphology. For instance, the strong tidal currents can be dangerous to divers and the low water visibility makes it difficult to operate underwater cameras. Moreover, the

rapid erosion and deposition processes cause major challenges in monitoring, or even locating the archaeological targets. Please note that many land or wetland areas were oceans back in the seventeenth century due to the massive sediment deposition carried by the Yanshui River. This results in limited water areas nowadays capable of ships or boats passing through.

With all the restrictions and challenges, this study also applies airborne-based geophysical survey methodology to acquire the overall information within the study area, including the land areas or fish farms where shipborne-based methods cannot be operated. A more detailed description of the geophysical instruments used is outlined in the “Resource” section. By integrated analysis of various geophysical data, we have built a database and developed a workflow for locating and monitoring the potential archaeological targets, which may give insights into the surveying strategies in other shallow water areas worldwide that are challenging for applying traditional archaeological surveying methods.

CASE STUDY

The case studies under consideration mainly are the previous geophysical surveys used for shallow water UCH identification. According to the previous experience, we realized that a new and integrated approach must be introduced to overcome the environmental challenges in Taijiang Waters.

Geophysical prospecting methods have been extensively used to locate buried antiquities in terrestrial sites for decades. This approach involves interdisciplinary studies which is also applicable and efficient to document the underwater environment in detail. Besides mapping the subsurface images, geophysical prospecting methods also provides critical physical properties of buried structures to complement archaeological research in a timely and costly efficient manner. The technological and methodological innovations upgraded it from an “amateur” activity to scientific research with a substantial contribution in the domains of past commerce and coast exploitations (Dobson 2005). However, the coastal and shallow underwater areas are still considered a “gray zone” or “white zone”, where different factors create a unique, constantly evolving, and challenging environment, sharing elements from both deep- water investigations and dry land surveys, which neither the equipment for deep-water exploration nor those used for dry land surveys can be directly employed in coastal areas (Galanidou, et al. 2020).

Generally, most of the efforts to reconstruct the hidden cultural heritage are mainly focused on deep-water environment explorations by acoustic geophysical methods that have been used to map ancient shipwrecks (Sakellariou, et al. 2007). The accessibility of shallow water archaeological sites rise a dilemma for the government, as it must decide whether to prioritize openness to the public or protect cultural assets. On the other hand, the water presence in submerged lands makes this area susceptible to various post-depositional or abandonment effects, as evidenced by the Taijiang Waters in Taiwan (Li 2018; Wang 2012). Perhaps that’s the reason why there is no coherent and efficient approach or technique so far for shallow-water heritage documentation, study, and protection, despite the availability of methods to investigate the cultural heritage in dry land or deep water (Papadopoulos 2021).

Since October 1966, several archaeological targets including a wreck site were discovered in the marine environment of Akko Harbour using a proton magnetometer, the technique has been widely used for underwater cultural heritage (Arnold and Clausen 1975). Today marine proton magnetometers have largely been replaced by optically pumped cesium vapor magnetometers and Overhauser effect magnetometers, both of which provide greater sensitivity and much faster cycle rates (Green 2014). Nevertheless, magnetic surveys may effectively detect shipwrecks but require a proper design operating in good weather conditions. And the beauty of a magnetic survey is that we don’t need to submerge the magnetometer before it can detect a shipwreck, most accessible wrecks that lie in shallow waters (<30m) are detectable from the surface (Steenkamp 2017). Generally, shipborne surveys are used for searching for wrecks in shallow waters and may be complemented by cheaply available side-scan sonar equipment. In Taijiang Waters in Taiwan, where some areas are difficult for the boat to access, we intend to take the advantage of a small drone equipped with a fluxgate magnetometer to offer good values to inspect the

submerged archaeological sites.

The sediment deposition in the Taijiang Water has greatly impacted human activities (Chen and Chang 2010). In the 17th century, the Taijiang Water was a natural port and was the administrative, economic, and cultural center of Taiwan. However, due to the sediment infill process of the Taijiang Water, it became more difficult to navigate ships in the nineteenth century, and eventually impossible for the ships to pass today. Figure 1 shows an example of the Taijing coast in the seventeen and twenty-first centuries. Due to the severe sediment deposition processes, numerous coastal communities that depended on shipping for their livelihood have declined.

To investigate the UCH in the Taijiang Waters, the Taiwanese government has conducted a shipboard general geophysical survey, including a multibeam echo sounder (MES), side scan sonar (SSS), sub-bottom profiler (SBP), and magnetic surveying (MG) (Lai 2018). Based on these datasets, several potential UCH targets were identified. After that, they conducted a detailed survey including underwater photography and resistivity image profiling, in addition to the four methods used in the general survey, to examine potential UCH targets. However, during the detailed survey, they observed a significant topographic change caused by rapid sedimentary processes. Either moving by the currents or buried by sediments, numerous previously identified potential UCH sites showed no obvious geophysical anomalies from the data collected from the detailed survey. Therefore, this study aims to introduce a joint data analysis technology to better detect and monitor potential UCH targets in this challenging site.



Figure 1. An ancient nautical chart by Dutch navigators (1652) overlaid with modern satellite images (Lai 2018) revealing the changing coastlines.

RESOURCES

To better identify the submerged archaeological targets (potential UCH) in Taijiang Waters, we integrated multiple the-state-of-art survey techniques to improve the certainty of potential target recognition. Our survey strategies and techniques in Taijian underwater geoarchaeological research not only increased the

density of the ship tracks to better image the seafloor topography, and profile the subsurface strata and magnetic features to recognize the potential targets; but also, we take the advantage of magnetic anomalies derived from airborne and shipborne geophysical surveys, to inspect the assessments which might be buried in the subsurface. Furthermore, we directly sample the channel sediments to investigate the sedimentological and environmental records to study the potential geological events in hundreds of years. The instruments and survey strategies we used are introduced as follows.

Shipborne-based geophysical survey

Based on the existing water depth and nautical chart data, the investigative scope of the Taijiang Waters includes intertidal zones with water depths ranging from 0 to 10 meters. Due to the shallow water depth and numerous obstacles such as oyster rafts near the coast, the operation uses a small boat, the *Wan Bao Long 58*, to reduce operational risks. The vessel has a total length of 14.60 meters, a width of 2.90 meters, a maximum draft of 0.74 meters, and a total tonnage of 11.75 tons.

(1) Side-scan sonar (SSS)

We use an EdgeTech 4125 side-scan sonar to collect dual-frequency seafloor images for the entire area while the survey line spacing and instrument's slant range were set at 25 meters, simultaneously.

(2) Multi-beam bathymetry (MB)

We predominantly use the RESON SeaBat 9001 multi-beam sounder with a survey line spacing of 10 meters to collect the bathymetry data. For the areas with water depth shallower than 1 meter, the Odom Echotrac CV100 single-beam sounder was used to fill the gap. Besides the relevant position, the angle deviation was obtained by superposition testing. All data were recorded in the collection software to obtain the relative position parameters of the instruments in 3D. For the sound velocity information, the vertical sound profile was measured at least 2 times a day. More measurements were conducted with significant changes in water temperature or salinity.

(3) Sub-bottom profiler (SBP)

We utilize the EdgeTech SB-216S tow-fish with a digital variable-frequency sonar sounder in 10 meters line spacing survey to image the subsurface strata.

(4) Magnetic Survey (MG)

Considering of the interference of the vessel, the SeaSPY used for shipborne magnetic survey was tied to a float and towed about 30 meters behind the vessel. And principally we set up the line space as 12.5 meters to derive better coverage of the data.

Airborne magnetic survey

With the airborne magnetic survey, we undertook a general survey around the Taijian area with 100% coverage and a detailed survey focussed along the river to better detect anomalies in those waters.

(1) General Survey

The general survey aims to mark the distribution of buried magnetic bodies. The operation height should be adjusted according to the environmental conditions. Therefore, a 25-meter design line spacing is used for this phase of the survey. The measurement height is set between 15-20 meters above ground level and adjusted according to the height of buildings, power poles, or windbreak trees in the survey area.

(2) Detailed Survey

Ideally, the survey line spacing is about 4 meters with a flying height of 4-8 meters above the ground/water level. The actual survey area was selected based on the results of the general airborne magnetic survey and the shipborne geophysical surveys.

FRAMEWORK

This study aims to identify potential UCH targets by applying geophysical methods for future monitoring and preservation. Considering the challenging survey environment, we applied an integrated analysis of different geophysical datasets including the MB, SSS, SBP, and magnetic methods.

In terms of geophysical data interpretation, the exposed targets were mainly identified through the interpretation of the SSS images. All the exposed targets show magnetic anomalies. However, due to the poorer resolution of the multibeam terrain data, the comparison results between exposed target objects and multibeam data target objects were inconsistent, and their shapes could not be identified through the multibeam depth data in this area. As fishing activities are prosperous in the Taijiang Waters, there are many oyster rafts or abandoned fishing gear in the river channel. Therefore, anomalous responses observed only from one single geophysical data were not used as the basis for identifying potential UCH target objects. Regarding the buried target objects, anomalous responses observed from SBP and magnetometer are the main criteria for interpretation.

After the integrated geophysical data analysis, we compared the potential UCH target locations with historical literature to have a preliminary idea from an archaeology perspective.

RESULTS

Besides collecting shipborne geophysical data including the SSS, MB, and MG, we further check the subsurface feature by SBP to define the suspicious targets (Figure 2). Then we combined the magnetic anomaly derived from airborne and shipborne geophysical surveys simultaneously to inspect the submerged assessment (Figure 3), the resources available to conduct the work include accurate frequency control on magnetic data acquisition and comprehensive geophysical integration for data interpretation. After integrating and interpreting various survey data in the Taijiang Waters, a total of 13 potential UCH targets were obtained (Figure 4), including 12 targets on the riverbed and 1 buried target. With these results, we are confident that our strategy of jointly analysing multiple geophysical data can increase the chance of identifying potential UCH sites and therefore benefit geoarchaeological research.

After integrating with previous survey results, seven underwater anomalies were correlated to the ancient Dutch shipwreck (Figure 4). This allows us to now embark on planning follow-up verification of each anomaly through archaeological research, for the purposes of confirming, or not, discovery and identifying each site. Through these activities we hope to preserve the historical underwater cultural heritage of the Taiwanese, and the endangered ecosystems of the treasured wetlands environments of the Taijiang National Park.

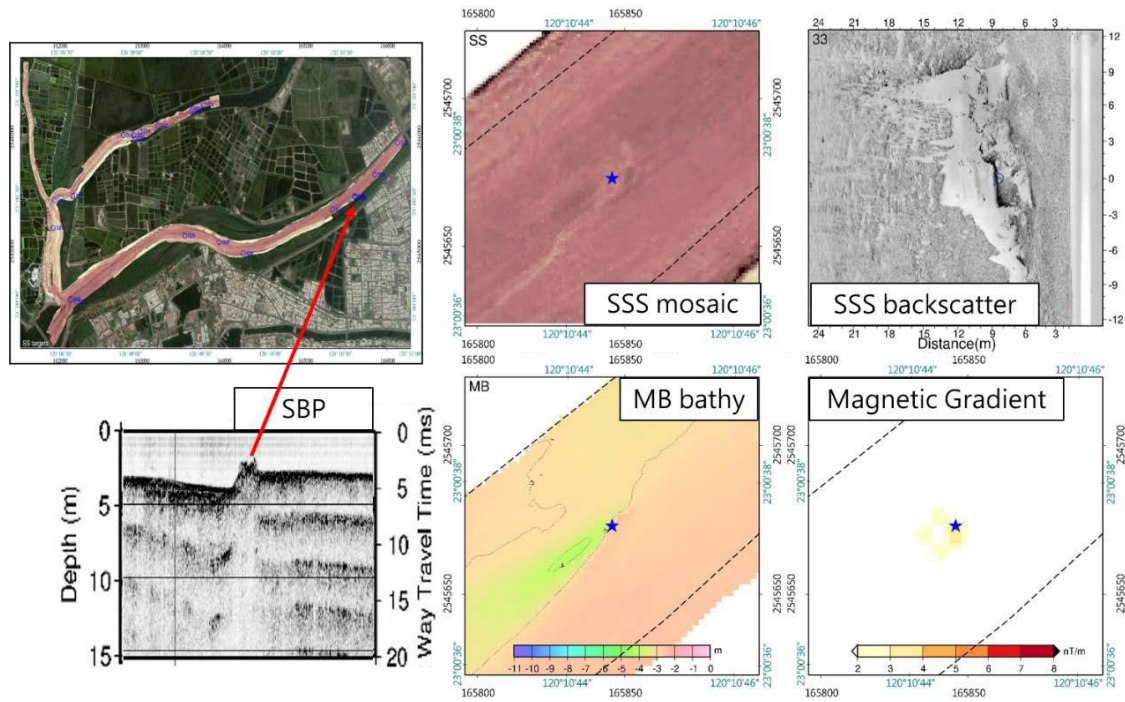


Figure 2. The four shipborne geophysical surveys we applied in the Yanshui River to investigate the suspicious targets.

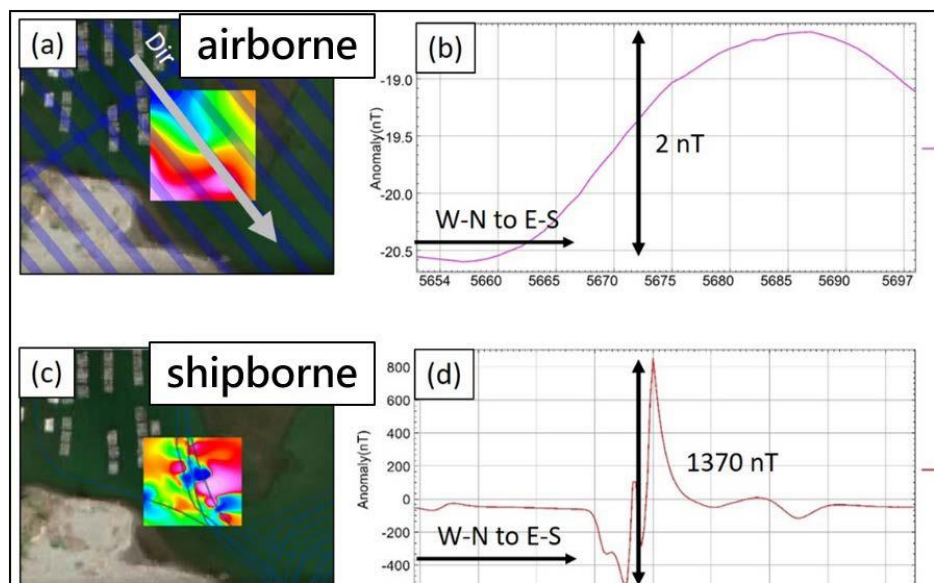


Figure 3. Magnetic anomaly derived from airborne and shipborne geophysical surveys to help inspect the submerged assessments.

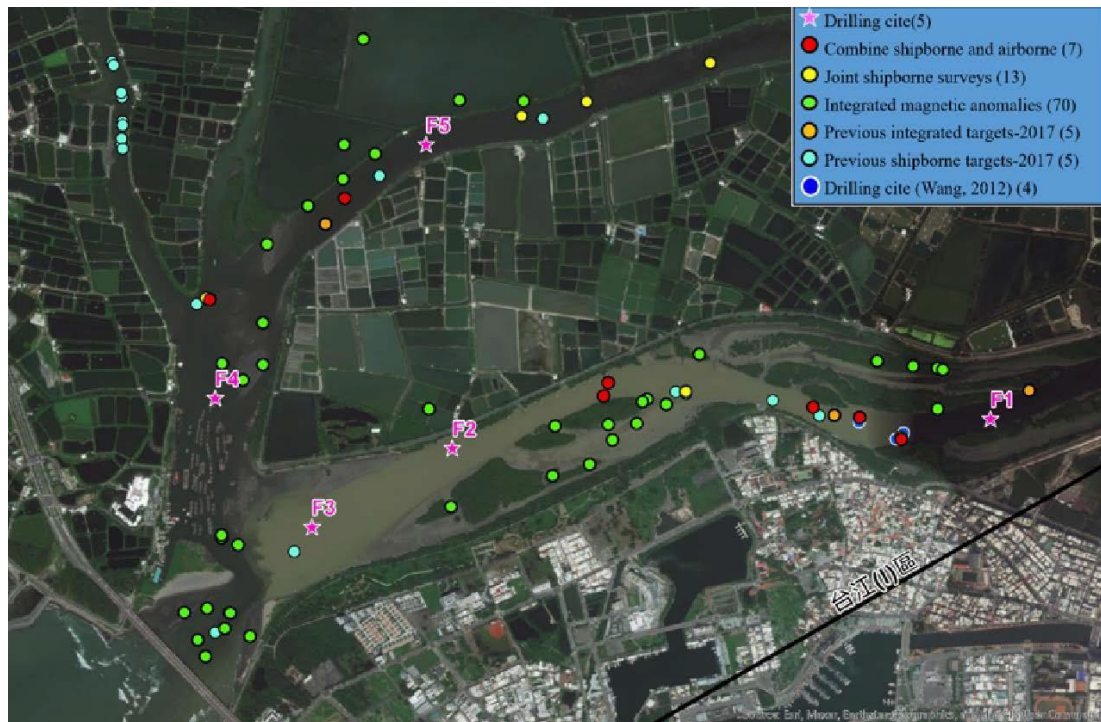


Figure 4. Map showing the locations of the potential UCH targets proposed by this study and previous studies with the planned drilling locations.

BIBLIOGRAPHY

Arnold III, J.B. and Clausen, C.J. A magnetometer survey with electronic positioning control and calculator-plotter system. *Historical Archaeology* 9, no. 1 (1975.), 26-40.

Chen, H. L., Chang, J. C. Terrestrialization process of the TaiJiang Water and its relations to human activities. *Geology of Taiwan* 29, no.4 (2010), 34-38.

Chiang, S. S. De Dagregisters van het Kasteel Zeelandia. *Tainan City Government Publications*. (In Chinese) Dobson, N.C., 2005, September. Developmental deep-water archaeology: a preliminary report on the investigation and excavation of the 19th-century side-wheel steamer SS Republic, lost in a storm off Savannah in 1865. In *Proceedings of OCEANS 2005 MTS/IEEE* (1999): 1761-1769. IEEE.

Galanidou, N., Dellaporta, K., Sakellariou, D. Greece: Unstable landscapes and underwater archaeology. In *Lakes of the World with Google Earth*; Springer: Cham, Switzerland, (2020): 371–392.

Green, J. The Application of Aerial Magnetometers in Maritime Archaeology. *International Journal of Nautical Archaeology* 43, no.2 (2014): 436-443.

Lai, C. P. Remote Sensing Exploration Project for underwater cultural heritage in the Dayun Port Waters. The Bureau of Cultural Heritage, Ministry of Culture, Taiwan. (In Chinese). 2018.

Li, C. L. The shipwrecks' historical documents collecting and analyzing of the Vereenigde Oost-Indische Compagnie. The Bureau of Cultural Heritage, Ministry of Culture, Taiwan. (In Chinese) 2018.

Papadopoulos, N. Shallow offshore geophysical prospection of archaeological sites in eastern Mediterranean. *Remote Sensing* 13, no. 7 (2021): 1237.

Sakellariou, D., Georgiou, P., Mallios, A., Kapsimalis, V., Kourkoumelis, D., Micha, P., Theodoulou, T., Dellaporta, K. Searching for Ancient Shipwrecks in the Aegean Sea: The Discovery of Chios and Kythnos Hellenistic Wrecks with the Use of Marine Geological-Geophysical Methods. *Int. J. Naut. Archaeol.* 2007.

Steenkamp, B. Application of the Magnetic Method to Explore for Shipwrecks on the South African Coast. Extended Abstracts - 15th SAGA Biennial Conference & Exhibition. 2017.

Wang, Y. The research of the 17th century Vereenigde Oost-Indische Compagnie shipwrecks types and distribution in the Taiwan Strait. *Studies of Underwater Archaeology*, Beijing: Science Press. Vol. 1 (2012): 163-188. (In Chinese)