



Design of an Integrated Experimental Teaching Case for the Active Sonar Target Detection System Based on the *Principles of Underwater Acoustics* Course

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Abstract. Based on the practical teaching demands of the *Principles of Underwater Acoustics* course for underwater acoustic engineering majors and in combination with the discipline construction and the strategic orientation of building China into a maritime power, this paper designs an integrated experimental teaching case for the active sonar target detection system. The proposed experimental case adopts a progressive teaching structure, which consists of three stages, including simulation-based validation, system construction, and system measurement. During the implementation of the experiment, this research initially employs the acoustic systems trainer (AST) to simulate the marine environment. Subsequently, this research further combines with experimental equipment, such as an experimental water tank and underwater acoustic transducer, to complete experimental tasks, such as validation of the active sonar equation, construction of the active sonar target detection system, and target strength measurement. As revealed by the teaching practice outcomes, the proposed design presents excellent scientificity and operability. Particularly, the implementation of this teaching case significantly deepens students' understanding of underwater acoustics theories while promoting their integration of theoretical knowledge and engineering practice. In parallel, the proposed design enhances students' comprehensive design, innovative thinking, and teamwork ability, further fostering their awareness of the national strategy of building China into a maritime power.

Keywords: Principles of Underwater Acoustics; Active Sonar; Integrated Experimental Design; Target Strength; Practical Teaching

1 Introduction

Sonar technology, as a core technology in ocean exploration and development, plays an irreplaceable role in diverse fields, such as ocean resource exploration, national defense security, and underwater navigation. Being a core required course of underwater acoustic engineering, the course *Principles of Underwater Acoustics* takes the sonar equation as its main line, covering several key theoretical contents, encompassing underwater acoustic propagation, target scattering, and sonar system design. Accordingly,

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the teaching quality of this course directly affects the formation of students' professional core competence. Currently, China is at a critical stage in building itself into a maritime power. Against this backdrop, it is imperative to cultivate technical talents within the field of underwater acoustic engineering with a solid theoretical foundation and prominent engineering practice ability^[1].

The traditional experimental teaching of the course *Principles of Underwater Acoustics* still takes the confirmatory experiment as its main form. Nevertheless, this teaching mode exposes certain shortcomings in practice, which are mainly reflected in the following three aspects. At first, a significant gap exists between the experimental environment and the realistic marine application scenarios. Current experimental teaching generally relies on simulation, lacking the operation and training of practical experimental equipment. Secondly, the experimental content exhibits the characteristics of relative fragmentation, which leads to its failure in systematically demonstrating the comprehensiveness and systematicness of sonar system design. Lastly, it adopts a relatively single teaching mode. During the actual teaching process, students are usually in a state of passively accepting knowledge, which leads to their lack of understanding of the actual meaning of the active sonar equation and its engineering application scenarios^[2]. Under these circumstances, it is urgent to build a comprehensive, well-designed, and practical experimental teaching system in combination with the professional construction objectives and engineering application requirements^[3].

In summary, the proposed experimental case design takes the design and application of an active sonar target detection system as a typical engineering application scenario. On such a basis, the proposed experiment constructs a multi-link progressive comprehensive experimental system. This experimental system realizes the organic integration of a series of contents, such as sonar equation theory, experimental equipment operation, system construction, and key parameter measurement. Furthermore, regarding the selection of experimental equipment, this research fully takes the actual demands of the project into account, giving priority to the selection of experimental equipment close to the actual engineering environment. Simultaneously, the experimental teaching adopts the teaching mode of group-based collaboration. While ensuring the professionalism and systematicness of experimental teaching, this mode is beneficial to cultivate students' innovative ability and teamwork spirit, thus laying a solid foundation for students to engage in the related fields of underwater acoustic engineering.

2 Experimental Teaching Design

2.1 Teaching Philosophy and Approach

Based on the teaching philosophy of integrating theory with practice, progressive competence development, and value-driven education, this research constructs a three-step progressive teaching framework covering theoretical validation, system design, and engineering application. During the experimental teaching, by comparing the passive sonar system as well as explaining the working principle, system structure, and typical applications of the active sonar system, the designed course helps students to gradually

establish a complete knowledge system of underwater acoustics. Moreover, it introduces realistic engineering cases of marine vessel detection and integrates ideological and political education elements into the teaching process, with a view to cultivating students' patriotism and their sense of responsibility for serving the nation's maritime development [4].

This experimental teaching adopts a group-based structure with five students per group and implements a team leader system. Concretely, under the coordination of the team leader, the team members complete various tasks, including theoretical combing, experimental scheme design, equipment operation, data processing, and experimental report writing. Structurally, the teaching process is designed as follows. Firstly, students sort out and summarize the experimental principles and basic theories according to the previous teaching contents, thereby clarifying the experimental objectives and technical routes. Subsequently, the students design the corresponding experimental scheme based on the principle of the active sonar equation. Furthermore, based on the phased arrangement, students complete simulation-based validation, system construction, and system measurement. In closing, students process and analyze the experimental data to write an experimental report. On the same note, students discuss and exchange the experimental outcomes and challenges in groups. Notably, the idea of teaching design is depicted in Figure 1.

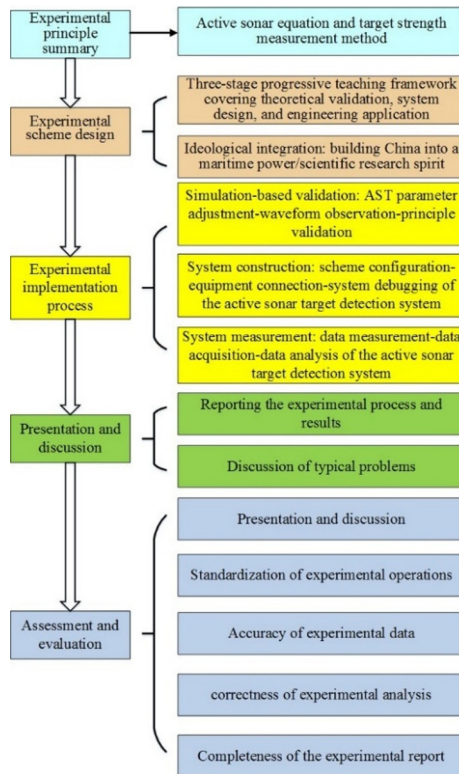


Fig. 1. Teaching Process Overview

2.2 Design of Experimental Content

The practical stage of this experimental case mainly includes three links: simulation-based validation, system construction, and system measurement. The foregoing three links complement each other and are closely interconnected in teaching design.

Simulation-based Validation.

Teachers in this session initially introduce the main functions and operation methods of the experimental equipment of the integrated acoustic systems trainer (AST), as shown in Figure 2. Subsequently, the teacher guides the students to build an active sonar target detection system using AST based on the basic principle of the active sonar equation. During this process, teachers instruct students to change the working parameters of the system to adjust the values of each sonar parameter. Meanwhile, students are taught to observe the changes in target echo waveform characteristics under different values to validate the influence exerted by sonar parameters on the working performance of active sonar target detection systems. Through this link, students are capable of forming an intuitive understanding of the composition of active sonar systems, further enabling students to understand the principle of the active sonar equation as well as the major factors affecting the performance of sonar systems. Simply put, this link helps to strengthen students' theoretical knowledge, so that students can initially possess the design ability of active sonar target detection systems, thus laying a solid foundation for the follow-up experiments.

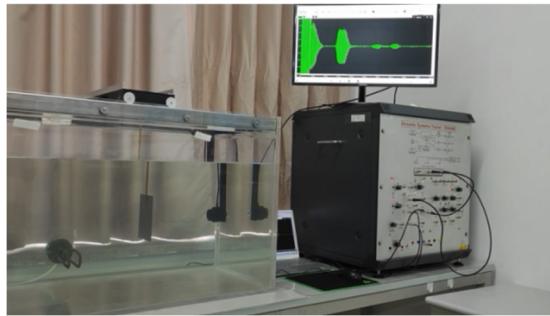


Fig. 2. Acoustic Systems Trainer

System Setup.

Based on the validation of the theoretical knowledge of the sonar equation, a scale experiment based on a stainless-steel experimental water tank is designed in this link. In this connection, the experimental tank measures 1.2 m in length, 0.8 m in height, and 0.75 m in width, as shown in Figure 3. With the active sonar equation as the criterion, teachers utilize the experimental water tank to simulate the reverberant marine environment. During the actual experiment, the transmitting transducer is used to simulate the active sonar pulse signal, whereas rigid spheres with different radii are employed to simulate underwater targets. In this foundation, this research designs an active sonar

target detection system, as illustrated in Figure 4. To maintain the stable operation of the system, teachers reasonably determine the parameters of the transmitted signal according to the size of the water tank and the target radius in the experiment to ensure the compliance of the sound field in the system with the far-field conditions, thereby endowing the system with certain anti-multipath interference ability. Furthermore, during the teaching process, teachers guide students to draw the schematic diagram of the system, complete the connection of dry-end and wet-end instruments and equipment, and select the appropriate transmitted pulse signal. Students can identify the interface reflected pulse and the target echo pulse in the oscilloscope, thus realizing the construction of the system. Moreover, the experimental system provides students with a variety of extracurricular experimental expansion conditions, including target distance measurement and target type measurement.



Fig. 3. Stainless Steel Experimental Water Tank

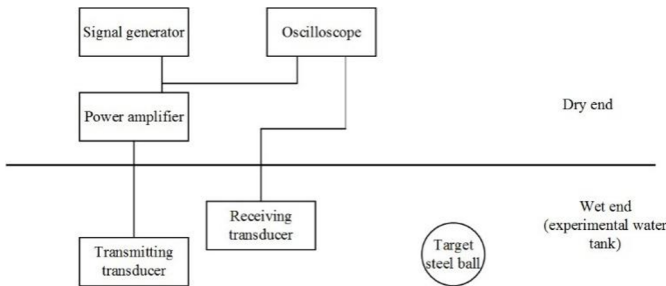


Fig. 4. Active Sonar Target Detection System Overview

System Measurement.

Following the construction of the active sonar target detection system in the previous link, this link adopts a direct measurement approach and a comparison approach to implement target strength measurement experiments for underwater targets, respectively. By changing the shape of targets, this research measures the target strength values under different shapes, comparing and analyzing the target strength results of diverse targets. Based on this, this research intends to derive the relationship between the target strength value and the target steel ball radius. Simultaneously, the teacher guides the students to think further about whether the comparison approach can be used to

measure the target strength of marine vessels. Through this experiment, students can master the basic methods of leveraging active sonar target detection systems to conduct engineering applications. In addition, the experimental process is helpful to cultivate students' ability to identify, formulate, and solve problems in the experimental process, further enhancing students' scientific literacy and exploration spirit.

2.3 Teaching Objectives

Through the foregoing teaching design, this research aims to achieve three-level teaching objectives: knowledge objectives, capability objectives, and quality objectives.

Knowledge Objectives.

Knowledge objectives mainly include: *a)* understanding the fundamental principles of the active sonar equation and the physical meanings of its parameters; *b)* becoming familiar with the operating principles and usage of equipment, such as the acoustic system trainer, underwater acoustic transducers, and oscilloscopes; and, *c)* mastering two approaches for measuring target strength, including the direct measurement approach and comparison approach.

Capability Objectives.

Capability objectives mainly include: *a)* enabling students to develop the capability to design and construct an active sonar target detection system; *b)* enabling students to acquire hands-on operational skills with typical underwater acoustic equipment; *c)* cultivating students' engineering practice abilities in terms of identifying, analyzing, and solving problems; and, *d)* enhancing students' abilities in teamwork and academic communication.

Quality Objectives.

Quality objectives mainly include: *a)* cultivating a rigorous and pragmatic scientific attitude as well as a spirit of excellence in engineering practice; *b)* stimulating students' research interest and innovative awareness within the field of underwater acoustic engineering; and *c)* strengthening students' sense of responsibility and commitment to contributing to national maritime development.

3 Experimental Principles

3.1 Active Sonar Equations

The active sonar target detection system realizes underwater target detection by transmitting acoustic signals and receiving target echoes, with its working process following the basic law of the sonar equation^[5-6]. The sonar equation serves as an important relation used to describe the working mechanism of sonar systems, which comprehen-

sively considers the unique phenomena and effects of underwater sound and their influence on the design and application of sonar equipment. Consequently, it can be employed to integrate the interaction among the seawater medium, the sonar target, and the sonar equipment. As a whole, the basic principle of the sonar equation can be summarized as: signal level - background interference level = detection threshold. In this case, the system is capable of completing the predetermined functions. Based on the basic principle of the sonar equation and the information flow of active sonar, the active sonar equation under a noise background can be further deduced as:

$$(SL - 2TL + TS) - (NL - DI) = DT \quad (1)$$

where SL stands for sound source level; TL represents propagation loss; TS stands for target strength; NL denotes marine environmental noise level; DI represents receiving directivity index; and DT denotes detection threshold. By changing the values of sonar parameters in the active sonar equation in turn, the influence exerted by sonar parameters on the working performance of the sonar system can be further validated.

3.2 Target Strength Measurement

Target strength is an important parameter used to characterize the ability of underwater targets to reflect acoustic signals, which is defined as the decibel ratio of incident sound strength at the target to echo strength at a distance of 1 meter from the target acoustic center [7]. The measurement of target strength typically adopts the direct measurement approach and the comparison approach.

Direct Measurement Approach.

Under the far-field condition, the monostatic sonar is placed in the far-field area of the target scattering field, with the distance between them being d , thereby measuring the echo signal amplitude E_h of the target. With the parameters of the transmitting system unchanged, the underwater acoustic receiving transducer in the monostatic sonar system is moved to the target position to measure the amplitude E_z of the direct wave signal. Without considering the sound absorption of the medium, the target strength value of the target to be measured, denoted as TS , can be determined as:

$$TS = 20 \lg d * E_h - 20 \lg E_z \quad (2)$$

Comparison Approach.

The monostatic sonar system is utilized to measure the echo strength EL_{h0} of the known target and the echo strength EL_{h1} of the target to be measured at the same position in the far field of the target scattering field. In this scenario, the strength value

of the target to be measured, denoted as TS , is defined as:

$$TS = EL_{h1} - EL_{h0} + TS_0 \quad (3)$$

where TS_0 represents the target strength of the known targets.

4 Experimental Teaching Implementation

4.1 Experimental Content and Procedures

The total duration of this experimental teaching case is 6 hours, in which simulation-based validation, system construction, and system measurement are arranged for 2 hours, respectively. The foregoing three stages correspond to three experimental subjects: the AST operation, the construction of the active sonar target detection system, and the target strength measurement of the active sonar target detection system.

AST Operation.

Based on the active sonar equation, this research initially connects the AST console panel according to the operation instructions and starts the AST. Subsequently, the transmitted signal is set as a pulse signal with a frequency of 100 kHz and a pulse width of 0.5 ms, thereby observing the waveforms of the transmitted signal and the echo signal in real-time.

This experiment adopts the control variable method. Specifically, during the experiment, this research varies the transmission power, target distance, water salinity (by adding 100 g of sea salt each time, for a total of three times), water temperature, background noise (controlled by activating the air pump), and target type (including a 10 cm × 10 cm steel plate, a 16 cm × 16 cm steel plate, and a plastic sphere with a radius of 6 cm). Under various experimental conditions, this research records the waveform characteristics of the echo and analyzes the variation law of the target echo waveform, thus validating the basic principle of the active sonar equation as well as the specific influence of sonar parameters on the system performance.

Construction of the Active Sonar Target Detection System.

During this experiment, teachers first instruct the students to independently implement the system construction according to the experimental equipment provided and the connection schematic diagram of the active sonar target detection system, while defining the setting range of each equipment parameter. Subsequently, under the guidance of teachers, the students arrange the wet-end equipment and place the underwater acoustic transmitting transducer, receiving transducer, and steel ball on the central axis of the experimental water tank, maintaining a water depth of 30 cm and a transducer-to-target distance of 60 cm, as illustrated in Figure 5. Regarding the signal configuration, this research sets the signal generator to output a continuous-wave (CW) pulse signal with an amplitude of 1 V, a frequency of 100 kHz, and a pulse width of 0.5 ms.

Concurrently, this research adjusts the output monitoring voltage to 10 V by utilizing a power amplifier. In the course of the experiment, students observe and identify the target echo signal through the oscilloscope, and fine-tune the direction of transducers to obtain the maximum echo amplitude.



Fig. 5. Wet-end Connection Diagram of the Active Sonar Target Detection System

Target Strength Measurement.

In this link, teachers instruct students to measure and compare the target strength of steel balls with different radii by direct measurement and comparison approaches, respectively. Firstly, regarding the operation of the direct measurement approach, students keep the parameters of the system unchanged and record the echo signal amplitude E_{h1} and background noise amplitude of the steel ball with a radius of 2 cm. Subsequently, with the target removed, the students move the receiving transducer to the target position to measure the amplitude E_{z1} of the direct wave signal. In the case of a steel ball with a radius of 3 cm, students repeat the above measurement steps and record E_{h2} and E_{z2} . On the other hand, in terms of the operation of the comparison approach, students take a steel ball with a radius of 2 cm as the standard target (known TS_0) and measure its echo amplitude EL_{h0} . With the measuring position unchanged, students continue to measure the echo amplitude EL_{h1} of the steel ball with a radius of 3 cm; otherwise, students measure the target strength of a steel ball with a radius of 2 cm with a 3 cm steel ball as the standard target. Throughout the measurement process, students are required to record the data in detail, with the measurement of each group being repeated three times. Meanwhile, taking the average value as the experimental result, the relative standard deviation (RSD) is calculated.

4.2 Discussion and Exchange

Following the operation of experimental subjects, students initially adopt different data representations in groups to process and analyze the measured data, further reporting the experimental process and results. Subsequently, each group exchanges views on the challenges encountered during the experiment and discusses the unresolved difficulties

to propose potential solutions. At last, under the guidance of teachers, each group discusses and analyzes such contents, including the relationship between target strength and target radius, the advantages and disadvantages of the direct measurement approach and comparison approach in target strength measurement, and the major influencing factors of experimental error.

4.3 Assessment and Evaluation

To test the effect of experimental teaching, this research designs a special assessment and evaluation link. During the process of teaching implementation, based on the basic principles of multi-instructor teaching, whole-process monitoring, and multidimensional evaluation, this research constructs the corresponding assessment scheme. To be specific, the total assessment score of this course is 100 points, including 30 points for each of the three experimental subjects and 10 points for the reporting and exchange link. Regarding each experimental task, a total-element assessment needs to be implemented. Specific scoring indices include four aspects: *a)* standardization of experimental operation, accounting for 5 points; *b)* accuracy of experimental data, accounting for 10 points; *c)* correctness of experimental analysis, accounting for 10 points; and *d)* completeness of the experimental report, accounting for 5 points. Particularly, regarding the evaluation of experimental operation, it is imperative to evaluate the actual operation of each student during the process of completing the individual division of tasks. In the case that an individual's experimental instrument is damaged due to improper operation, the overall experimental score of the individual's group is recorded as zero.

Based on the reports and summaries of each group, teachers can further effectively determine students' understanding of the concept of the active sonar equation. Meanwhile, teachers can evaluate whether students' individual experimental operation ability has been improved, and whether students have enhanced their sense of cooperation and scientific literacy during the whole experiment. Through the above evaluation, teachers are capable of testing the achievement of teaching objectives in this experimental teaching case.

4.4 Implementation Outcomes

The implementation of this case teaching significantly improves students' theoretical knowledge and practical ability. As revealed by the results of the extracurricular survey, 92% of the students can accurately explain the physical meaning of the active sonar equation, while 88% of the students can independently complete the system construction and parameter measurement. Compared with the traditional experimental teaching mode, the proposed teaching mode prominently improves students' engineering practice ability and innovation consciousness. Moreover, during the implementation of the experiment, students address diverse practical problems, such as equipment connection, signal identification, and error analysis, through group cooperation. By the foregoing practice process, students' teamwork ability and problem-solving ability have been effectively exercised.

4.5 Distinctive Innovations

The distinctive innovations of this case can be summarized as the following three aspects. Firstly, in terms of theoretical teaching, the abstract theory is visualized in this case. By designing an AST operation experiment, this case transforms the original abstract formula into an observable and operational experimental process, thus deepening students' understanding of the theory of active sonar equation and stimulating their interest in learning. Secondly, regarding the experimental design, this case introduces the idea of scale experiments. Focusing on the active sonar equation, this case not only constructs an active sonar detection system based on the scaled water tank but also further exercises students' practical operation ability by guiding students to complete the system construction process. Lastly, the designed system presents excellent expansibility. The designed active sonar target detection system can be further expanded on the existing basis to support students in implementing extracurricular expansion experiments, such as target distance measurement.

5 Conclusions

Taken together, based on the core knowledge of the course *Principles of Underwater Acoustics* and combined with practical engineering application scenarios, this research designs a three-stage progressive integrated experimental system covering theoretical validation, system design, and engineering application. During the implementation of the experiment, by combining the AST theory validation experiment with the actual system construction practice, the proposed experimental case reduces the cost and safety risk of experimental teaching, whilst ensuring the engineering authenticity of the experimental process. The results of teaching practice demonstrate that the proposed experimental case can effectively make up for the shortcomings of the traditional experimental teaching mode, thus realizing the deep integration of theoretical knowledge and engineering practice. Simply put, the designed experiment case not only significantly improves students' professional skills and innovative ability but also cultivates their scientific literacy and awareness of building China into a maritime power.

During the subsequent teaching practice, this research will further optimize the experimental content. More exactly, at first, this research intends to introduce a large-scale pool as an experimental teaching venue, thus comparing and analyzing the influence exerted by diverse experimental environmental conditions, such as a pool or water tank, on the working performance of sonar systems. Furthermore, this research plans to add extended modules, including multi-target detection and complex marine environment simulation. Concurrently, this research will introduce the teaching mode of combining virtual simulation technology with physical experiment, further enhancing the comprehensiveness and innovation of the experimental teaching. Through the above improvement measures, this research aims to provide more powerful support for the training of underwater acoustic engineering professionals.

References

1. Li J, Wang Y, Chen Z, et al. Spatiotemporal Analysis of Sonar Detection Range in Luzon Strait[J]. *Journal of Marine Science and Engineering*, 2024, 12(7): 1191.
2. Foeller J, Vecchiotti A, Turo D, et al. Undergraduate engineering education with hands-on experimental acoustic field work[J]. *Journal of the Acoustical Society of America*, 2023, 154(4-Sup):4.
3. Wang H. L., Wang Y., & Lei B. Research and Exploration on an Innovative Practice-oriented Talent Cultivation Model under the Strategy of Building China into a Maritime Power[J]. *University*, 2024, (07): 103-106.
4. Li H., Li L., & Liu S. Z. Challenges and Countermeasures for the Construction of Curriculum Ideological and Political Education from the Perspective of New Engineering[J]. *Heilongjiang Researches on Higher Education*, 2023, 41(04): 157-160. DOI:10.19903/j.cnki.cn23-1074/g.2023.04.016.
5. Schäfer I, Ehrlich J. High-performance calculation of the acoustic backscattering strength based on the Kirchhoff high-frequency approximation[C]. *Proceedings of the 7th Underwater Acoustics Conference and Exhibition (UACE 2023)*, Kalamata, 2023: 303-310.
6. Zhu Z. Y., Zhang C. H., Yin L., Chi C., & Gao S. G. Azimuth and Range Estimation of Active Sonar Targets for a Horizontal Array in Deep-sea Acoustic Region[J]. *Acta Acustica*, 2025, 50(3): 693-702.
7. Liu Y, Zhang M, Liu H, et al. Low-frequency transducer with a periodic displacement amplification structure based on 3D printing[J]. *Applied Acoustics*, 2023, 204: 109232.

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