J. COMBIN. MATH. COMBIN. COMPUT. 127b (2025) 9691--9706

Journal of Combinatorial Mathematics
and Combinatorial Computing
www.combinatorialpress.com/jcmcc

Combinatorial Press

Key technology research on ultrasonic ranging of double center hole of air and underwater cast pile based on adaptive filtering algorithm

Yang Zhang[1], Luyao Wang[1,✉], Hongping Xie[1], Kaixin Gu[1], Zijian Ye[1], Cheng Yan[1]

[1] *State Grid Jiangsu Electric Power Co., Ltd. Construction Branch, Nanjing, Jiangsu, 210000, China*

ABSTRACT
To overcome the obstacle of ranging by using the same type of ultrasonic transducer in two medium such as water and air, whose sound wave transmission characteristics are of significantly different, this paper proposed a dual medium ultrasonic ranging scheme, with the application background of cast-in-place piles' borehole diameter measurement. Based on the analysis of media's influence mechanism on ultrasonic ranging performance, a high-sensitivity weak signals conditioning circuit is constructed, with front-end amplifier, bandpass filter, demodulator, back-end amplifier and lowpass filter, which enables the ultrasonic transducer dedicatedly designed for underwater ranging can work in the air. On this basis, by designing a dual channel signal conditioner and increasing the ultrasonic emission power, the problem of ultrasonic ranging in air and underwater using unique type of transducer is solved, and the media in which ranging is ongoing can be distinguished at the same time. To verify the scheme's effectiveness, an experimental platform is built and ranging experiment is conducted in both air and water. The result proves that the expected ranging range and accuracy can be achieved under both media conditions, which lays theoretical foundation and provides engineering approach for similar scenarios.

Keywords: ultrasonic ranging, ultrasonic transducer, signal conditioning, dual medium, cast-in-place piles

1. Introduction

The influence of external conditions on the quality of concrete construction cannot be ignored. Pouring concrete piles is a kind of engineering project with strong concealment, but because of the many factors that have a certain influence on the quality of the piling operation, all the links of its operation process need to be strictly required, and every kind of influencing element should be

✉ Corresponding author.
E-mail address: wongsixrone@163.com (L. Wang).
Received 03 March 2024; Revised 20 April 2024; Accepted 10 November 2024; Published Online 16 April 2025.
DOI: 10.61091/jcmcc127b-532

considered in a thorough way [1-3]. If a little careless or lax measures, quality accidents will occur, such as pile shrinkage, concrete segregation, pile breakage, etc., which will affect the schedule and cause an increase in the construction cost [4-5]. Therefore, it is necessary to pay great attention to and strictly control the quality of concrete work to prevent accidents as much as possible or reduce the adverse effects caused by accidents, in order to contribute to the smooth implementation of the project.

Taking underwater casting as an example, the main facility utilized for underwater casting of concrete is steel conduit, and steel pipe concrete columns are mostly used for columns and temporary vertical support columns of foundation pits in the inverse method of construction, which is generally a column and a pile structure [6]. Temporary steel pipe concrete column doubling as a permanent structural column of the project, the concrete grade in the steel pipe column is higher than the concrete grade of the pile body, which needs to be poured twice to become a living, and the construction precision requirements are high [7-9]. In addition, the number of underwater drilled piles is large and the length is long, and the good or bad quality of the operation of pouring concrete underwater has a great degree of influence on the quality of the piling project, which in turn has a significant impact on the construction quality of the whole project, for which it is necessary to accurately select the appropriate construction technology to ensure that the quality of the construction of the drilled piles meets the relevant requirements [10-13]. Because ultrasonic waves are not affected by light, smoke, electromagnetic interference and other factors in the process of propagation, they have obvious advantages over other ranging methods, and are widely used in realizing the accurate construction of air and underwater cast pile drilling [14-17].

To solve the problem on sequential distances measurement of air and underwater with the same ultrasonic transducer, this article focuses on the measurement of borehole formation in cast-in-place piles. A technical solution is proposed to use underwater specialized ultrasonic transducers and design signal processing circuits for each medium to measure the bore diameter of cast-in-place pile in the air and underwater.

2. The problem of dual medium ultrasonic ranging

In order to illustrate the requirements and problems of dual medium ultrasonic ranging, the measurement of borehole diameter in cast-in-place piles is taken as an example for analysis in this section. It can also provide reference for similar application scenarios.

2.1. Principle of hole diameter measurement for cast-in-place piles

Cast-in-place pile is a common construction technique which is widely used in power system, transportation, and civil construction applications. Due to the crucial impact of construction quality on the upper structure and even the entire application, it is necessary to accurately measure the parameters such as hole depth, diameter, verticality, and sediment thickness after pile hole formation and before concrete pouring, for timely detect and correct engineering quality problems and avoid economic losses.

Relevant standards have been developed for detection, equipment, and conditions of hole quality. Taking aperture measurement as an example, the recommended methods in the standard include mechanical contact method, ultrasonic method, and probe cage method, among which ultrasonic is the popular method.

The scheme of a borehole diameter measurement system for cast-in-place piles using ultrasonic method is shown in Figure 1. It mainly composed of an ultrasonic probe, a towing mechanism (winch), and a measure control host. Multiple sets of ultrasonic transducers are uniformly arranged in the form of separate or integrated transceivers at different orientations of the probe, used to detect the distance from the center of the probe to the hole wall and adaptively calibrate the center position of the probe. The position of the probe in the axial direction of the borehole is controlled by the winch drag, and corresponding information is fed back through the rotary encoder of the winch.

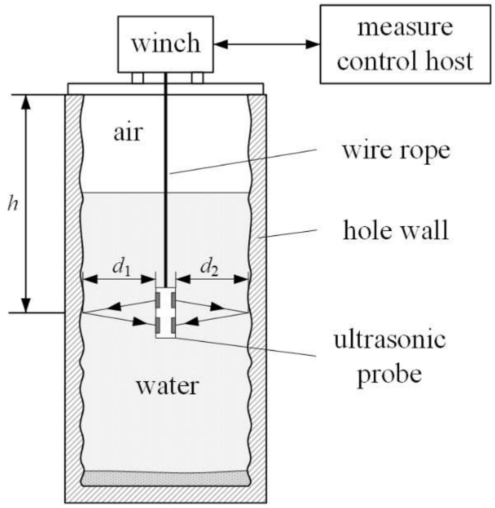


Fig. 1. Structure of borehole diameter measuring system for cast-in-place piles

Depending on the scale of the construction, the hole diameter of the cast-in-place pile is generally within the range of 500-3500mm, and the depth is within the range of 30-100m. Under such depth conditions, groundwater usually accumulates in the hole, which is particularly common in southern regions.

It can be seen from the above detection process and conditions, ultrasonic ranging is a key technical part in this detection scheme, especially in achieving coherent and accurate distance detection in media with huge characteristics differences such as air and water.

2.2. Dual medium ultrasonic ranging approach and feasibility analysis

Ultrasonic transducers are usually designed for specific applications, so in order to achieve distance detection in the air or underwater, dual probe, combination probe, and universal probe three implementation schemes can be considered, as shown in Figure 2.

The dual probe scheme uses two types of transducers A and B, where probe A is used for distance measurement in an air environment without entering the water, and B probe is used for underwater distance measurement and is not used in air. This solution is effective, but it requires two independent towing mechanisms for the probe and precise detection of the water surface position, which can lead to complex system structure and high cost, making it difficult to apply.

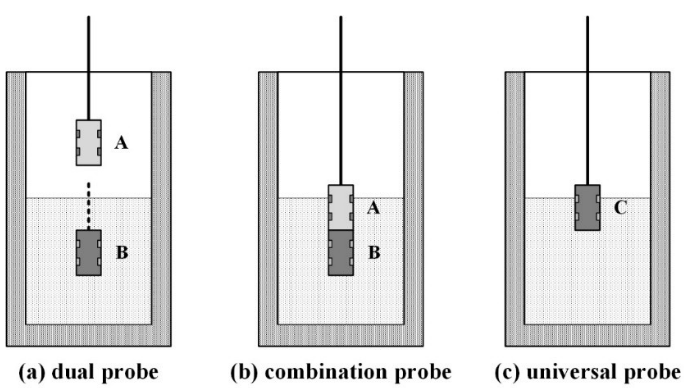


Fig. 2. Approach of dual medium ultrasonic ranging

The combination probe scheme is to combine two types of transducers suitable for air and underwater distance measurement into a whole at the probe structure level or transducer housing level, sharing a set of towing mechanisms. The key to this plan is to modify the transducer for distance measurement in the air to meet the IP68 protection level requirement underwater. However, this also brings about a significant theoretical flaw, that is, the transducer after structural modification may no longer meet the performance requirements for distance measurement in the air. The implementation method of the distance measurement function in this scheme is the same as that of the dual probe scheme, so in addition to the advantage of reducing the design difficulty of the towing system, there is not only no improvement in the complexity of the probe design, but also more potential engineering problems.

The universal probe solution is to use the same ultrasonic transducer to design a probe that can be used for both air and underwater distance measurement. The selected transducer itself should have an IP68 protection level, which means using a specialized underwater distance measurement transducer to avoid potential problems caused by increased protection levels. Obviously, this solution is the most reasonable because it can achieve seamless integration of two medium ranging functions, thereby simplifying the system structure, reducing costs, and creating favorable conditions for applications.

Since the selected transducer already has underwater ranging capability, it only needs to solve its ranging problem in the air. Based on this issue, the rest parts of this article will analyze the signal characteristics of air and underwater ranging from the perspective of transducer characteristics and the influence of transmission media, and ultimately form a technical solution for dual medium ranging.

3. The Influence and Mechanism Analysis of Transmission Media on Ultrasonic Ranging

3.1. Composition and working principle of ultrasonic ranging system

The ultrasonic ranging system usually consists of a transmitting transducer T, a receiving transducer R, as well as amplification and driving of the response, signal processing, and other components. It uses a microcontroller to generate pulse, process echo signal, as shown in Figure 3.

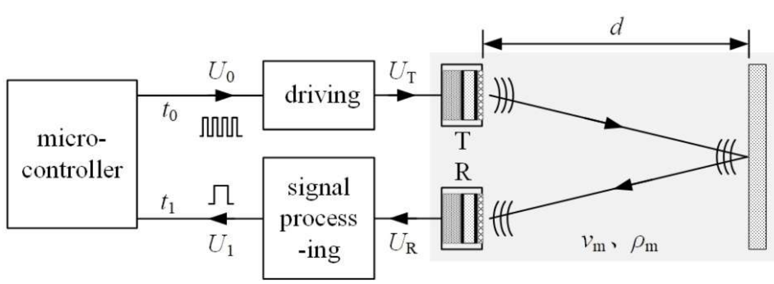


Fig. 3. Composition and working process of ultrasonic ranging system

The core of an ultrasonic transducer is a piezoelectric or magnetostrictive element covered with metal plates on both sides, which is stacked with matching layers, damping layers, etc. and encapsulated in a housing. The piezoelectric or magnetostrictive element of transmitter T generates mechanical resonance under the excitation of pulse train U_T, which in turn excites the harmonic vibration of the dielectric particles, forming ultrasonic waves of a specific frequency of longitudinal waves.

When the transmitting beam encounters an obstacle, refraction and reflection of the wave occur at the interface. The reflected beam travels through the transmission medium in the same longitudinal wave form and reaches the receiver R, causing it to output an echo signal U_R, which is then processed by a conditioning circuit to form a timing stop pulse U_1. Compared to the distance d to be measured, the distance between T and R can be ignored. Therefore, with medium sound velocity v_m, the distance to be measured can be obtained by using the time difference $t_1 - t_0$ between the start and stop timing of emission, which can be expressed as

$$d = (t_1 - t_0)v_m / 2 \tag{1}$$

where d is the distance to be measured. t_0 and t_1 are the starting emission time of ultrasonic waves and the arrival time of echo signals, respectively. v_m is the propagation speed of ultrasonic waves in the medium.

3.2. Signal Transmission Model of Ultrasonic Ranging System

By using the electromechanical equivalent analysis method, the process of ultrasonic ranging can be represented by the electromechanical equivalent network. as shown in Figure 4.

In Figure 4, R_0 and C_0 are the static resistance and capacitance of the transducer, respectively, where R_0 is very large and can generally be ignored; k_m is the electromechanical conversion coefficient of the transducer; M_m, C_m, and R_m are the equivalent mass, equivalent compliance coefficient, and mechanical resistance of the transducer, respectively; M_r and R_r are the equivalent resonance mass and radiation acoustic resistance determined jointly by the transducer and the medium, where the loss on R_r represents the energy radiated or received in the form of sound waves; k_r is the power transmission coefficient that takes into account the medium transmission loss, beam angle, and obstacle reflection conditions.

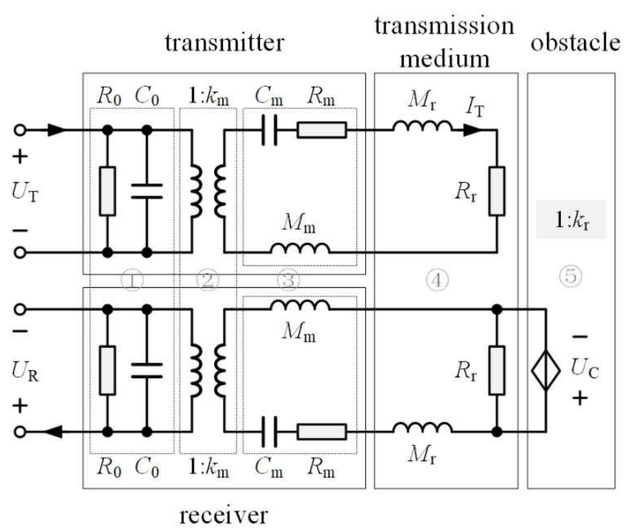


Fig. 4. Ultrasonic ranging system's electro-mechanical equivalent network

Usually, the models of the transmitter and receiver are the same, or even integrated, so they are represented by the same structure and parameters in Figure 4. The expressions for these parameters were written with the Rayleigh Ritz method in reference, excluding k_r.

The ranging process can be described in stages using Figure 4. The transmitter radiates a beam with a power of P_T through the acoustic resistance R_r at the transmitting end under the excitation voltage U_T. The beam reaches the receiver after being transmitted through the medium and reflected by obstacles, and the attenuated power is $k_r P_T$. This part of the power can be equivalent to the result of the controlled voltage source U_C acting on the acoustic resistance R_r at the receiving end. The equivalent network of the receiver ultimately outputs the echo voltage U_R.

It can be seen from the above process, the influence of transmission medium and reflection conditions on distance measurement is only reflected through M_r, R_r, and k_r. Therefore, the following part will analyze their effects on the radiation power P_T and echo voltage U_R.

3.3. The Influence of Dielectric Characteristics on Radiation Power and Echo Voltage

Without loss of generality, assuming that the excitation element of the transducer is a simply supported disk structure with a diameter as D, and the angular frequency of the excitation voltage U_T is ω, the resonance mass M_r and radiation resistance R_r of the transmission medium can be expressed as

$$\begin{cases} M_r = \dfrac{\kappa D^3}{3H}\rho_{\mathrm{m}} \\ R_r = \dfrac{\pi D^4\omega^2}{32}\cdot\dfrac{\rho_{\mathrm{m}}}{v_{\mathrm{m}}} \end{cases} \tag{2}$$

where v_m and ρm are the sound velocity and density of the transmission medium, respectively. k and H are the near-field kinetic energy factor and vibration factor determined by the transducer structure. When v_m and ρm are given, the radiation resistance R_r can be expressed as

$$R_r = K_{\mathrm{p\_m}}\omega^2 \tag{3}$$

where K_{p_m} is called power radiation factor

$$K_{\mathrm{p\_m}} = \frac{\pi D^4}{32}\cdot\frac{\rho_{\mathrm{m}}}{c_{\mathrm{m}}} \tag{4}$$

From the transmitter circuit, the current equation can be written as

$$\dot{I}_{\mathrm{T}} = \frac{k_{\mathrm{m}}\dot{U}_{\mathrm{T}}}{(R_{\mathrm{m}}+R_{\mathrm{r}})+\mathrm{j}\omega[M_{\mathrm{m}}+M_{\mathrm{r}}-1/(\omega^2C_{\mathrm{m}})]} \tag{5}$$

The radiation power of the transducer can be expressed as

$$P_{\mathrm{T}} = \frac{k_{\mathrm{m}}^2U_{\mathrm{T}}^2R_{\mathrm{r}}}{(R_{\mathrm{m}}+R_{\mathrm{r}})^2+[\omega(M_{\mathrm{m}}+M_{\mathrm{r}})-1/(\omega C_{\mathrm{m}})]^2} \tag{6}$$

The echo voltage equation can be written as

$$\dot{U}_{\mathrm{R}} = \frac{k_{\mathrm{m}}}{j\omega C_0}\cdot\frac{\dot{U}_{\mathrm{C}}}{R_{\mathrm{m}}+\mathrm{j}\omega[M_{\mathrm{m}}+M_{\mathrm{r}}-1/(\omega^2C_{\mathrm{m}})]} \tag{7}$$

where U_C meet the constraint as

$$\frac{U_{\mathrm{C}}^2}{R_{\mathrm{r}}} = k_{\mathrm{r}}I_{\mathrm{T}}^2R_{\mathrm{r}} \tag{8}$$

Combined (5)(7)(8), the relation between U_R and U_T is

$$U_{\mathrm{R}} = \frac{k_r^{1/2} k_{\mathrm{m}}^2 R_r}{\omega C_0 Z_{\mathrm{R}} Z_{\mathrm{T}}} U_{\mathrm{T}} \tag{9}$$

where Z_T and Z_R are the impedance sizes of the transmitting and receiving parts, respectively. The expression is

$$\begin{cases} Z_{\mathrm{T}} = \sqrt{(R_{\mathrm{m}} + R_{\mathrm{r}})^2 + [\omega(M_{\mathrm{m}} + M_{\mathrm{r}}) - 1/(\omega C_{\mathrm{m}})]^2} \\ Z_{\mathrm{R}} = \sqrt{R_{\mathrm{m}}^2 + [\omega(M_{\mathrm{m}} + M_{\mathrm{r}}) - 1/(\omega C_{\mathrm{m}})]^2} \end{cases} \tag{10}$$

Based on a comprehensive analysis of the above formulas, the following two conclusions can be drawn:

1) The wave velocity v_m and density ρ_m of the transmission medium have a significant impact on the radiated power P_T and echo voltage U_R, which are reflected by M_r and R_r.

2) Under the premise that the transducer and ranging environment have been determined, the amplitude and frequency of the excitation voltage will also have a significant impact on P_T and U_R, and the voltage amplitude should be increased as much as possible.

3.4. Quantitative analysis of the influence of medium on ranging performance

In order to visually demonstrate the influence of media on ranging performance, this section takes a specific transducer as an example and substitutes specific values into the above formula to compare the relationship between radiation power and echo voltage under the conditions of air and water media.

Due to the many factors that affect the power transmission coefficient k_r, in order to highlight the key points, it is assumed that it is independent of the transmission medium and a fixed value of 0.1 is taken. The effective value of the excitation voltage is set to 100V, and the frequency is continuously adjustable.

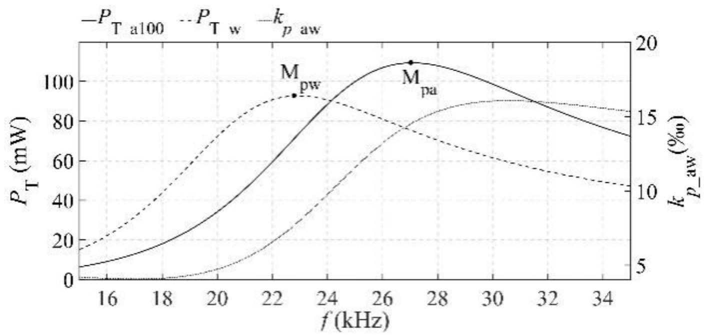
The excitation element adopts a PZT-4 simply supported disk with a diameter of D=20mm and a thickness of h=3mm; The density and sound velocity of air are 1.23kg/m^3 and 340m/s, respectively, while the density and sound velocity of water are 103kg/m^3 and 1480m/s, respectively. The parameters of the transducer and medium in Figure 4 are calculated using the method described in, and the results are listed in Table 1.

Table 1. Typical parameters of ultrasonic transducers and transmission media

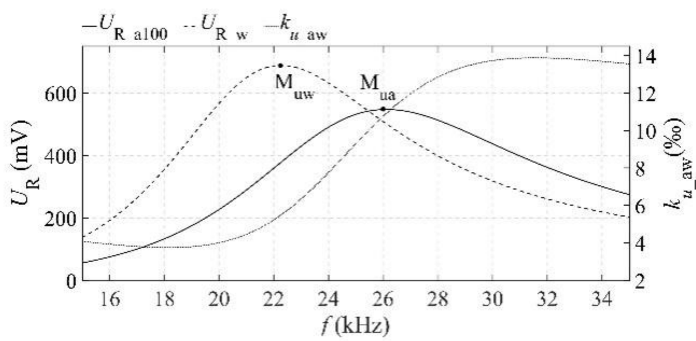
Symbol	Parameters	Value	Unit
C_0	Static capacitance of transducer	3.785	nF
M_m	Equivalent mass of transducer	9.962	mH
C_m	Equivalent compliance coefficient of transducer	3.974	nF
R_m	Mechanical resistance of transducer *	803.1	Ω
k_m	Electromechanical conversion coefficient of transducer	0.2122	—
M_{r_a}	Equivalent resonant mass in air	4.116	μH
M_{r_w}	Equivalent resonant mass underwater	3.347	mH
K_{p_a}	Power radiation factor in the air	5.785×10^{-11}	$\Omega \cdot s^{-2}$
K_{p_w}	Underwater power radiation factor	1.061×10^{-8}	$\Omega \cdot s^{-2}$

* R_m is related to the material, structure, process, and load conditions, and is difficult to quantitatively determine. Here, it is converted based on the underwater resonance frequency corresponding to $R_{r\_w} = 201\Omega$ and the mechanical acoustic efficiency $\eta_{ma} = 20\%$.

Take these parameters to equations (6) and (9) and use MATLAB software plotting the frequency dependent curves of the transducer radiation power and echo voltage in air and water, as shown in Figure 5.



(a) Variety of P_T



(b) Variety of U_R

Fig. 5. Radiated power and echo voltage in the air and underwater

During the calculation process, the radiation power P_T and echo voltage U_R in the air did not exceed 2% underwater. Therefore, the values in the air were multiplied by 100 for display in the same graph, and a100 was added to their subscripts to distinguish them.

In order to display the relative relationship between the quantities in the two media, taking the underwater quantity as the base value, multiply the quantity in the air by 1000 and calculate the ratio between them, which are represented in the figure as k_{p_aw} and k_{u_aw}, respectively.

With the analysis in Figure 5, three conclusions can be drawn as follows:

1) During the process of excitation frequency variation, there are obvious peak points in the radiation power and echo voltage of air and underwater. The peak radiation power underwater is 92mW, with a frequency of 22.93kHz; 1.09mW and 27.15kHz in air. The peak value of the echo voltage underwater is 689mV, with a frequency of 22.35kHz; In the air, it is 5.48mV and 26.15kHz.

2) The radiation power and echo voltage at the peak point in air are only 1.46% and 1.76% of underwater, respectively. Compared to underwater, the signal at the peak point in air is weaker, which is a weak link that needs to be focused on in applications and the reason why a single type of transducer is difficult to achieve dual medium ranging.

3) Even underwater, the radiation power and echo voltage level of the transducer are relatively low, and measures need to be taken to enhance them in the design of application systems.

4. Design of Dual Media Ultrasonic Ranging Scheme

In response to the problem of weak radiation power and echo signals of underwater specialized ultrasonic ranging transducers in air, this section proposes solutions from two aspects. One is transducer selection and excitation parameter design. The other one is signal conditioning design, to achieve high-precision ranging and seamless connection between air and underwater.

4.1. Design of transducer and its driving part

Due to the relatively low radiation power level of individual excitation elements, priority should be given to selecting underwater specialized ranging transducers with array structures and choosing models with higher excitation voltages. Following this approach, the transducer that meets the expected ranging performance indicators was ultimately determined, with the main parameters and appearance listed in Table 2.

Table 2. Typical parameters of the selected ultrasonic transducers

Parameters	Value	Appearance
Frequency	90kHz±5%	
Minimum impedance	200Ω±20%	
Equivalent capacitance	1900pF±20%@1kHz	
Ceiling voltage	2200V$_{PP}$	
Sensitivity *	5.0V@500Vpp	
Beam angle	half-power angle 18°±10%	
Maximum pressure	1MPa	
Protection grade	IP68	

* Under the conditions of a driving voltage of 500Vpp and a distance of 0.7m underwater, the shooting method is used

Taking into account the factors of circuit design and implementation, the working voltage of the transducer is set to 700V$_{PP}$, which is obtained by driving a 1:30 ratio medium extraction boosting transformer.

The excitation signal adopts a pulse train with adjustable number and frequency of pulses, and the parameters can be optimized based on the received echo signal strength during the measurement stage. To simplify the system parameter design and avoid switching between different media, the excitation signal frequency is uniformly set according to the peak point of the echo signal in the air, as the Mua point in Figure 5, without overly focusing on the underwater working point, because the underwater echo signal is strong enough.

4.2. Design of echo signal conditioning

The radiation power of underwater specialized transducers used in air ranging is on low level, and the echo signal is weak. Moreover, the radiation power difference between underwater and air is significant, which makes it difficult to simultaneously meet the signal conditioning needs of both applications. Therefore, based on the characteristics of the echo signals in the two media, the dual channel echo signal conditioning scheme is determined through theoretical analysis and actual measurement comparison, as shown in Figure 6.

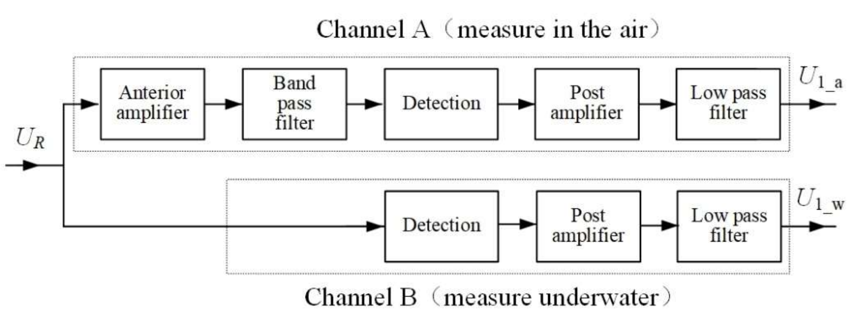


Fig. 6. Dual channel signal conditioning scheme

In Figure 6, the preamplifier in channel A is a gain programmable amplifier composed of an instrument amplifier and a digital potentiometer. It has the characteristics of high input impedance, wide frequency band, small temperature drift, and high accuracy. It has been widely used in weak signal amplification. The gain of this stage is designed within the range of 10-250 times, and is positive definite during the actual measurement stage, which can meet the needs of amplifying weak signals at the level of 1-200mV.

Due to the weak echo signal and low signal-to-noise ratio in the air, a bandpass filter with the same center frequency as the excitation frequency is used to filter out background noise to the maximum extent and improve the signal-to-noise ratio after high magnification amplification in the previous stage.

After unipolar conversion of the signal in the detection stage, a fixed gain post amplification is performed, and impedance matching function is achieved. Finally, the excitation frequency component is filtered out by a low-pass filter, and the signal U_{1-a} that can be used for A/D conversion is output in the form of an envelope.

Due to the strong underwater echo signal and high signal-to-noise ratio, channel B is not equipped with a preamplifier and bandpass filter similar to channel A. The echo signal is directly processed from detection to simplify the system design.

One characteristic of the design of the conditioning part is the use of high-frequency schottky diodes with a nominal conduction voltage drop of about 0.3V in the detection stage. It can be used to automatically distinguish between underwater and air ranging scenarios

1) When measuring distance in the air, due to the weak echo signal U_R, it cannot reach the detection voltage threshold, so the output voltage U_{1_w} of channel B always remains around 0V; Only when U_R passes through the pre amplification and filtering stage of channel A, can it exceed the detection voltage threshold and output an effective ranging signal U_{1_a}.

2) When measuring underwater, due to the strong echo signal exceeding the detection voltage threshold, channel B will output an effective ranging signal U_{1_w}, while U_{1_a} will always be in a saturated state due to large gain in channel A.

4.3. Design of echo signal conditioning

On the basis of the transducer drive and echo signal conditioning, a high-performance microprocessor and upper computer are configured to design a dual medium ultrasonic ranging system, as shown in Figure 7.

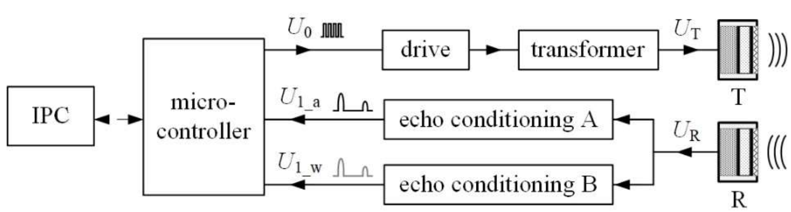


Fig. 7. Structure of the dual medium ultrasonic ranging system

In Figure 7, a 16-bit dual core microprocessor is used to implement excitation pulse train generation, dual channel echo signal conditioning and control, high-speed synchronous sampling of two signals, threshold comparison, and distance measurement information extraction. It has the ability to collect underwater and airborne echo signals at rates of 2MHz and 0.5MHz respectively. It continuously stores waveform data within a range of 2m from the measured distance. The corresponding ranging resolution can reach the level of 0.4mm.

By utilizing the collected waveform data, it is possible to optimize and adjust the frequency and number of pulses of the excitation signal, as well as adaptively adjust the gain of the echo conditioning channel. Using the wavelet transform algorithm discussed in, the distance information to be measured is accurately extracted from the waveform data.

By bidirectional communication between the CAN-FD interface of the microprocessor and the computer, the hole diameter detection system for cast-in-place piles shown in Figure 1 can be constructed.

5. Experimental results

To verify the effectiveness of the proposed dual medium ranging scheme, the hardware and software were completed based on the above design and parameters. On this basis, the experimental platform of the dual medium ultrasonic ranging system is shown in Figure 8.

In Figure 8, 6 sets of ultrasonic ranging drive and conditioning circuits were designed on the measurement and control board, which is controlled by a dual core microprocessor. A set of ultrasonic transmitting and receiving transducers is arranged in the sink, and a movable reflector is used to set the distance to be measured. The interface for distance measurement experiments was designed on the computer using VS and Qt software. The waveform of the distance measurement process is displayed on a four-channel oscilloscope.

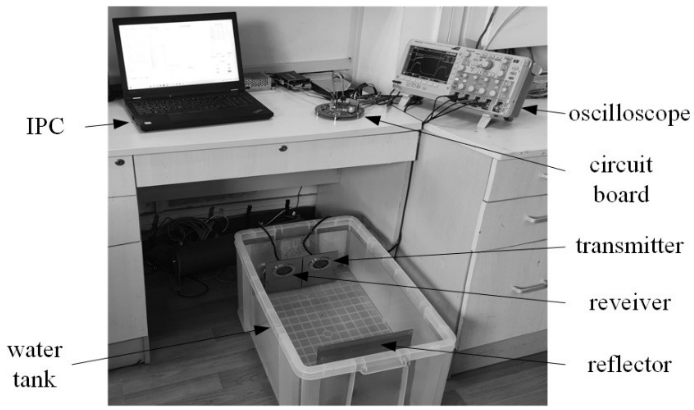


Fig. 8. Experimental platform of dual medium ultrasonic ranging system

The underwater ranging experiment with a set distance of 400mm is shown in Figure 9. Channel 1 of the oscilloscope is connected to the driving pulse U_0, and channels 2 and 3 are respectively connected to the conditioning circuit outputs U_{1_a} and U_{1_w} for air and underwater distance measurement. The definitions of these signals are consistent with Figure 7, and the signal selection for subsequent experiments is the same.

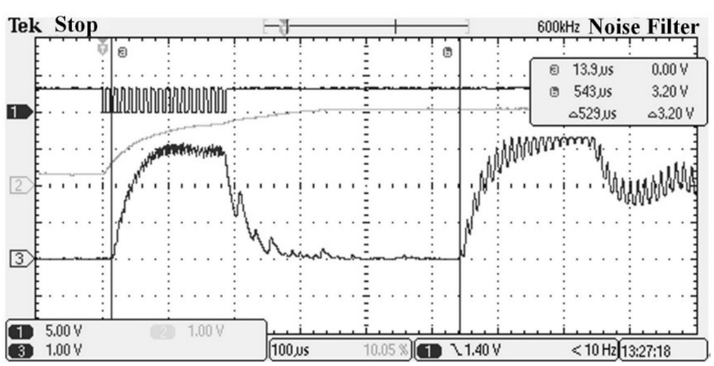
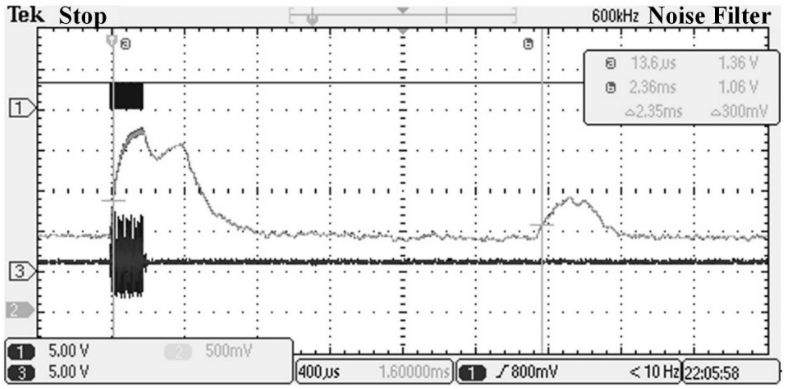


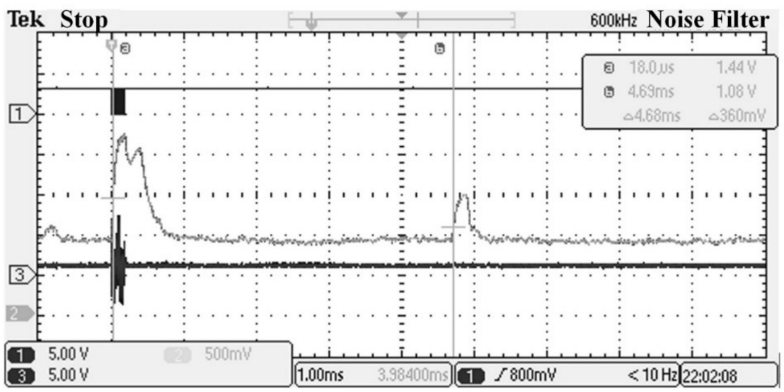
Fig. 9. Underwater ranging waveform of 400mm

It can be seen from the Figure 7, when pulses appear in U_0, two pulses appear successively in U_{1_w}, corresponding to the time of ultrasonic emission and echo signal arrival, respectively. The time difference between the two pulses is 529 μs. According to the wave speed of 1480m/s underwater, the measured distance is 391.5mm, which is consistent with the set distance of 400m.

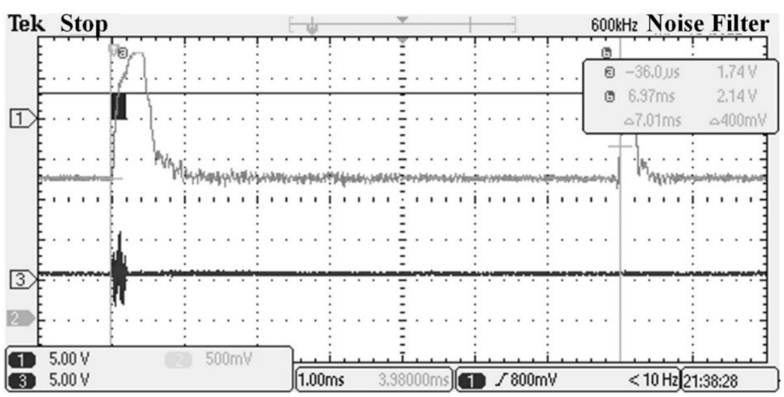
The distance measurement experiment in the air is similar to Figure 8, but a water tank is no longer needed and the distance setting range is larger and more flexible. Therefore, distance measurement experiments were conducted with a step size of 100mm, ranging from 200 to 2000mm in sequence. The waveforms at four distances are shown in Figure 10.



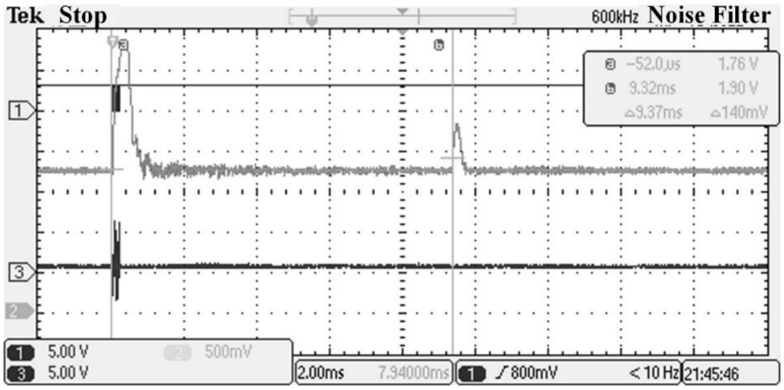
(a) d=400mm



(b) d=800mm



(c) d=1200mm



(d) d=1600mm

Fig. 10. Ranging waveform of different given distances in the air

Corresponding to the distances to be measured of 400 mm, 800 mm, 1200 mm, and 1600mm, the time intervals between the first and second pulses can be seen from Figure 10 are 2.35ms, 4.68ms, 7.01ms, and 9.37ms, respectively. With the sound velocity of 340m/s in air, the measurement results are 399.5mm, 795.6mm, 1191.7mm, and 1592.9mm, respectively. The deviations from the set distances are within reasonable experimental conditions. This confirms that after adopting the signal conditioning scheme proposed in this article, the underwater specialized ranging transducer can be used for distance measurement in the air and can ensure relatively high accuracy.

It can be seen from Figure 9, that U_{1_a} is under saturation during the underwater distance measurement process, without showing the pulse of the echo. From Figure 10, it can be seen that during distance measurement in the air, U_{1_w} remained in a zero-voltage state except for the interference of the excitation pulse, and no echo pulse appeared. This confirms that the proposed signal conditioning scheme has the ability to distinguish ultrasonic transmission media.

6. Conclusion

This paper proposes a dual medium ultrasonic ranging scheme, which takes into account the transmission characteristics of air and underwater ultrasonic waves. The method adopts two different structures and gains of echo signal conditioning channels, while increasing the ultrasonic transmission power, to achieve the ranging function of underwater dedicated ultrasonic ranging transducers in air. It solves the problem of unity and coherence in the ranging process in dual media.

The experimental results show that the platform designed according to the scheme can achieve high detection accuracy in both air and water, and has the ability to automatically identify the medium, which confirms the feasibility of the scheme.

Acknowledgment

This research was supported by the 2024 Science and Technology R&D Project (Science and Technology Project of State Grid Jiangsu Electric Power Co., Ltd.) (JF2024005).

References

[1] Cao, Z., & Wei, Y. (2021). Research and Design of Over-irrigation Control System for Underwater Pouring Concrete of Pile Foundation. In IOP Conference Series: Earth and Environmental Science (Vol. 647, No. 1, p. 012087). IOP Publishing.

[2] Yin, J., Yang, J., Bai, M., Lv, T., & Suo, Y. (2020, November). Discussion on Construction Technology and Quality Management of Underwater Cast-in-Place Concrete Pile. In IOP Conference Series: Earth and Environmental Science (Vol. 598, No. 1, p. 012022). IOP Publishing.

[3] Fang, M., Yu, L., & Tan, Y. (2021, March). Methods used to construct underwater pile caps on the Hong Kong–Zhuhai–Macao Bridge. In Proceedings of the Institution of Civil Engineers-Bridge Engineering (Vol. 174, No. 1, pp. 3-12). Thomas Telford Ltd.

[4] Wei, Y., & Cao, Z. (2019, December). Research and application of over-filling monitoring technology for underwater cast-in-place piles. In IOP conference series: earth and environmental science (Vol. 371, No. 2, p. 022066). IOP Publishing.

[5] Thi, B. P. H., Nguyen, V. D., Vuong, Q. V., & Dang, H. M. (2024). Enhancing the Load-bearing Capacity of a Damaged Hydraulic Structure Rehabilitated by Underwater Concreting. Engineering, Technology & Applied Science Research, 14(4), 15651-15655.

[6] Allen, S. N., & Moore, G. A. C. (2016). Construction methodologies and challenges for marine concrete structures. In Marine Concrete Structures (pp. 115-133). Woodhead Publishing.

[7] Sun, L., Liu, X., Xu, J., Li, S., Li, M., Hu, C., ... & Yao, S. (2024, August). Quality Control of Bored Piles of Cross-river Bridges Pile Foundation Construction. In Proceedings of the 2024 3rd International Conference on Applied Mechanics and Engineering Structures (AMES 2024) (Vol. 34, p. 50). Springer Nature.

[8] Guo, J., Gao, L., Xu, X., & Xia, J. (2023). Development of Reinforced Concrete Piles in the Lower Yellow River, China. Sustainability, 15(19), 14500.

[9] Chang, X., Sun, J., Wang, S., Kang, A., & Peng, J. (2022). Horizontally loaded steel pipe piles anchored in bare and hard rock under deep water condition: Parametric analysis. Ocean Engineering, 266, 112715.

[10] Mo, T., Li, G., Zhang, W., Deng, D., Chen, Z., Wang, Y., ... & Zong, H. (2021, November). Study on construction technology of bored pile foundation in karst cave and soil cave. In 4th International Symposium on Power Electronics and Control Engineering (ISPECE 2021) (Vol. 12080, pp. 980-984). SPIE.

[11] Wang, X., Wang, X., Li, J., Liu, D., Zhang, Y., & Jiang, D. (2023). Field Test Study of Performance of Bored Piles in Collapsible Loess. Applied Sciences, 13(24), 13113.

[12] Luan, S., Wang, F., Wang, T., Lu, Z., & Shui, W. (2018). Characteristics of gravelly granite residual soil in bored pile design: An in situ test in Shenzhen. Advances in Materials Science and Engineering, 2018(1), 7598154.

[13] Fang, W., Gu, Y., Wang, F., Xing, G., & Li, G. (2021, June). A Hybrid Pile Foundation Application to Subsea PLEM for CALM System in Super Soft Clay. In ISOPE International Ocean and Polar Engineering Conference (pp. ISOPE-I). ISOPE.

[14] Liu, H., Liu, W., Sui, S., Xu, H., & Wang, J. (2022). Dynamic monitoring technique of bored pile pouring process based on multi-frequency ultrasound. Journal of Civil Structural Health Monitoring, 12(2), 411-425.

[15] Wang, Z., Peng, Z., Yan, Y., Liu, K., & Wu, Z. (2024). Field test of internal visualization of deep-water pile foundation using ultrasonic waves. Structural Health Monitoring, 14759217241286432.

[16] Wang, J., Xu, H., Wang, B., Zou, J., & Liu, H. (2022). Accurate detection technology of super long bored cast-in-place pile concrete pouring thickness based on ultrasonic inclined plane reflection measurement. Measurement, 198, 111314.

[17] Zhang, S., Zhu, Y., Xiong, W., Rong, X., & Zhang, J. (2024). Bridge substructure feature extraction based on the underwater sonar point cloud data. Ocean Engineering, 294, 116770.