IS-PHYS Lab1

Lab1: Speed of Sound in Water

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Abstract

This experiment used the standing wave method to measure the speed of sound in water at indoor temperature. We measured the function generator, sound velocimeter, and oscilloscope to measure the wavelength and calculated the experimental sound speed v= 1537.76(m/s), with a percentage error of 2.75%. The theoretical speed $v_{theoretical}$ =1495.34 (m/s). The result is acceptable; however, the experiment procedure still has many places where we can improve to reduce the error.

1 Introduction

In our life, sound of water is widely used in various realms. Among all forms of underwater radiation, soundwave performs best. Soundwave in water is widely used in underwater communication, navigation, detection, and monitoring, making a great contribution to marine development and military aspects.

In this lab, we used the standing-wave method to calculate the experimental value of sound speed in water by measuring the wavelength. Then we made an error analysis with the data and estimated its accuracy with the theoretical value of the sound speed at the indoor temperature we calculated with the formula.

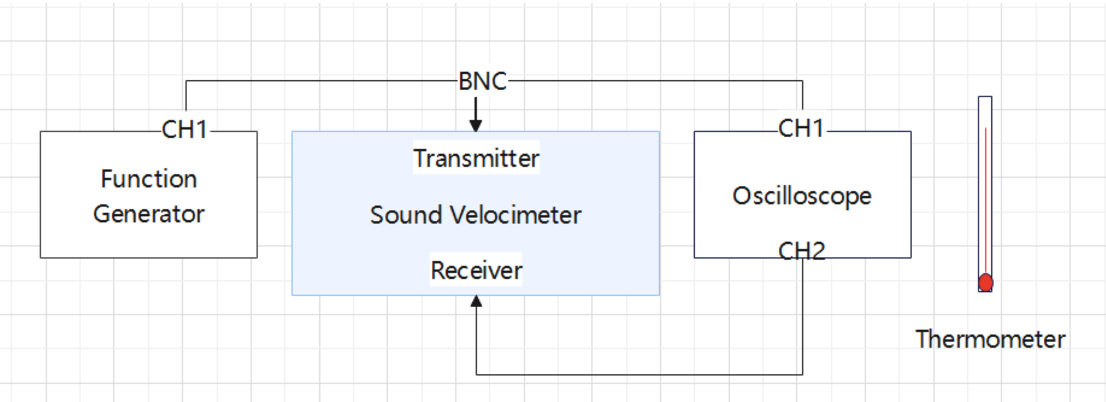

Figure 1: Experimental setup for measuring the wavelength

2 Data

In the experiment of measuring the sound speed in the water, we used the standing wave method to measure the half-wavelength λ, then we used the formula (the frequency (f) is set at 70k Hz by function generator and wavelength (λ) is measured)

$$v = f\lambda$$

to calculate the speed (v).

To reduce experimental error, we applied the linear regression method to get a more accurate wavelength.

The standing wave method works as follows: The corresponding soundwave and the soundwave radiated by the transmitter overlap, and the superposition wave changes in a periodical way and get its maximum amplitude twice (when they are in phrase) in every period.

Starting from a local maximum amplitude, 'i' is the ith time we saw the standing wave reaches its next local maximum amplitude. l_i is the reading number we read from the digital vernier caliper. According to the definition of the standing wave, the slope b_1 is half the wavelength.

$$l_i = b_0 + b_1 i \quad (b_1 = \lambda/2)$$

Using linear regression to the dataset, we get the regression function:

$$l_i = -0.78394 + 10.98451\, i$$

So the wavelength λ= 0.21968 (m) and the experimental speed of sound is v= 1537.76(m/s)

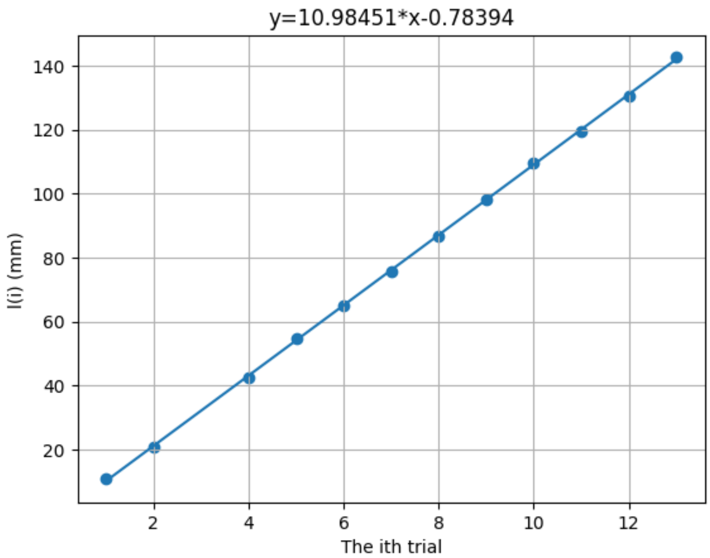

Figure 2: The linear regression graph of l(i) in terms of i

3 Analysis and Discussions

Theoretical value

Firstly, we calculated the theoretical sound speed in pure water at indoor temperature. In pure water, the speed of sound v is

$$v = \sqrt{\frac{K}{\rho}}$$

where K is the bulk modulus of water and ρ is the density of water. The bulk modulus (Pa or N/m^2) and the density of water can be calculated using empirical formulas

$$K = -1.2348 \times 10^5 T^2 + 1.3659 \times 10^7 T + 1.9692 \times 10^9$$

$$\rho = -5.1636 \times 10^{-3} T^2 + 7.3115 \times 10^{-3} T + 1.0001 \times 10^3$$

where T is the temperature T=25.5°C measured by terameter.

Replace the variable with numbers, we had: $v_{theoretical}$ =1495.34 (m/s)

Error Range

The uncertainty of frequency is $U_f \approx 0.05\% f$

The uncertainty of wavelength can be calculated using the "t-value" in statistics:

$$U_\lambda = U_{b_1} = ts_{b_1} \approx \left(1.959 + \frac{2.406}{(n-2) - 1.064}\right) s_{b_1}$$

where s_{b_1} is the standard deviation of the slope b_1 and n is the number of data points.

The combined uncertainty of speed of sound is then given by

$$U_v = v\sqrt{\left(\frac{U_f}{f}\right)^2 + \left(\frac{U_\lambda}{\lambda}\right)^2}$$

Therefore, $v' = v \pm U_v = 1537.76 \pm 61.73 = [\,1476.13, 1599.39\,]\ \mathrm{m/s}$

And the percentage error of the experimental v is 2.75%, which is reasonable.

And the R^2=0.99 of linear shows that the linear regression is well modeled and indicated that the error of data we measured is relatively acceptable

Error Analysis

The error can be caused by different reasons.

Firstly, it maybe caused by experimental apparatus. The function generator may generate fluctuant ultra-wave due to the voltage of the generator is not constant, so the point we read the from the digital vernier caliper may not be accurate. The digital vernier caliper may not give the accurate number, and the further it goes, the bigger absolute error it may have.

Secondly, the error may be caused by how students read the maximum point. The maximum amplitude is not so easy to identify. Although it is reduced by linear regression, there is still large error in this step. We lacked the i=3 point because the maximum amplitude there is too hard to identify, so we deserted the data at i=3.

Thirdly, the movement of the sound wave receiver may affect how the water. If the water is not stilled for enough time, the water is not ideally static, so the flow of water may lead to error.
Fourthly, the bobble on the transmitter and receiver may leads to a smaller speed. In this experiment, we made sure there is no bubbles on the receiver and transmitter. But to testify, we also made an experiment with bobbles on both receiver and transmitter. And the v_{bubble} =1535.28 (m/s), which is a little smaller than v= 1537.76(m/s). This may because the bubbles reduced the actual sound path(which is analogue to 'optical path'), so the speed is a mixture of sound speed in water an air, so it is smaller.

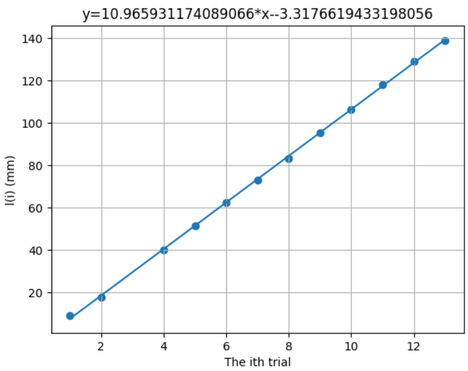

Figure 3: The graph of data of l(i) with i

4 Conclusion

During this lab, we have measured the experimental value of the sound speed in the air and compared it with the theoretical value calculated by the equations. The result is acceptable but can be further improved. This experiment can be improved by applying other methods to monitor the maximum amplitude points and using vernier caliper of higher precision. Or the experiment can be improved by using the minimum amplitude points to record the numbers instead of the maximum amplitude points. By doing this we can adjust the maximum sensitivity and better recognize the minimum amplitude points.

Raw data

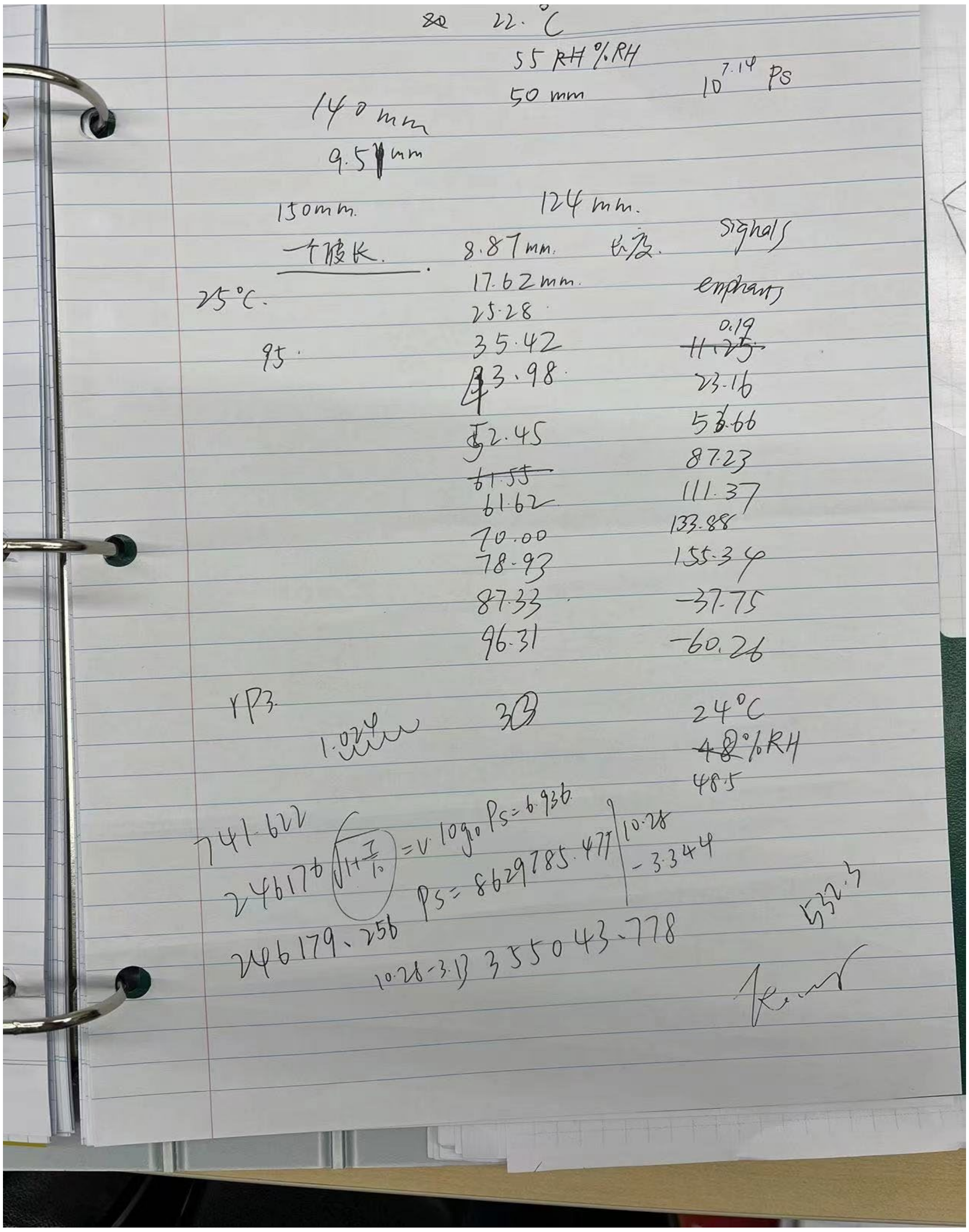

Figure 4： The raw data collected in class

in air			In water	with bubble	without bubbles	
1	8.2	8.42	1	9	1	10.89
2	16.62	8.98	2	17.9	2	20.96
3	25.6	8.7	4	40.09	4	42.5
4	34.3	8.97	5	51.6	5	54.62
5	43.27	8.57	6	62.63	6	65.12
6	51.84	8.92	7	72.88	7	75.78
7	60.76	9.05	8	83.4	8	86.66
8	69.81	8.64	9	95.31	9	98.16
9	78.45	8.73	10	106.49	10	109.52
10	87.18	8.81	11	118.11	11	119.58
11	95.99	9.61	12	128.89	12	130.64
12	105.6	8.07	13	138.89	13	142.8
13	113.67					

Figure 5: Data printed in excel