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Improved Frequency Modulation Method Based on Sphere-String Mechanical Antenna

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ABSTRACT

In addressing the challenging problems of underwater communication, mechanical antenna (MA) provides a new direction for greatly reducing the size of low frequency communication equipment and breaking through the Chu-Harrington limit [1,2]. MA refers to the generation of low-frequency electromagnetic waves by mechanically driving materials with strong electric or magnetic fields. This direction has attracted many researchers from fields such as materials, mechanics, and mechanics to conduct research. Various forms of MA currently exist, but research on their modulation methods remains limited. The modulation methods of MA primarily include amplitude modulation, frequency modulation, and phase modulation [3]. Frequency modulation is widely used due to its excellent anti-interference properties. This study proposed and experimentally proved a method of encoding using the transient information of modal transformation based on the sphere-string mechanical antenna. The modulation method greatly improves the transmission speed of information and provides more ideas for the modulation method of MA.

KEYWORDS

Mechanical antenna; frequency modulation; sphere-string structure; transient information

1 Research Methods

This study is based on the sphere-string mechanical antenna designed in reference [4]. It used the combination of frequency and time for encoding, which is shown in Fig. 1(a). The modulation method takes a long time to transmit information. As shown in Fig. 1(a), it can be seen that in addition to frequency, information in the middle of the frequency switching will also be sent. Therefore, the research proposes encoding using transient information from different modal transformation processes.

The received signals were bandpass filtered and then subjected to Hilbert transform. The Hilbert transform extracts the instantaneous frequency of a signal by constructing a complex analytical signal. Fig. 1 (b) shows the instantaneous frequency information of the received signal. For the six switching processes of three frequencies, ten experiments were conducted for each switching process. To identify the unique parameter distinguishing six modal transformations, the experimental data were analyzed. The vibration equation of the sphere-string structure was used to simulate these transitions, considering key factors such as wave theory, boundary conditions, and material properties. By adjusting parameters like tension and linear density, mode transitions were observed. Special attention was given to the variations of the unique parameter across different modal transformations, demonstrating their effectiveness in identifying distinct modal transition processes.

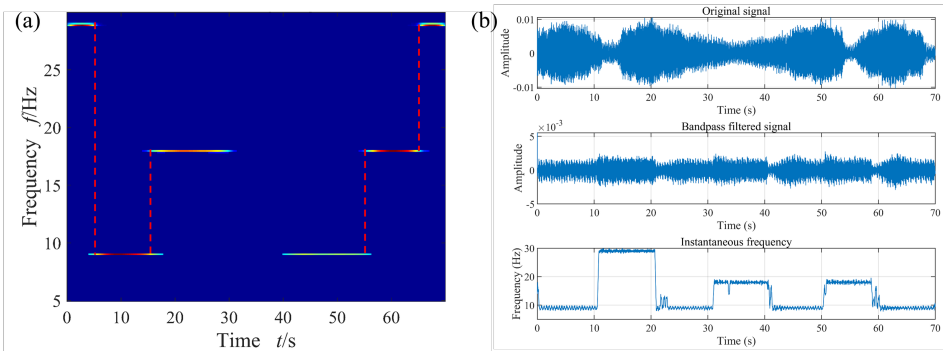

Figure 1: (a) Schematic diagram of frequency-time coding method. (b) Received signal processing results diagram.

3 Results and Discussion

The data processing results indicate that the maximum frequency switching speed of the six modal switching processes are within a certain range, which do not overlap with each other. This transient information can be used for encoding, as shown in Fig. 2. The minimum stable time T required for modal switching of the sphere-string structure was experimentally measured and set as the duration of each frequency. The encoding method in Fig. 1 (a) will stay at each frequency for a long time and requires monitoring the duration of these frequencies to ensure accuracy. This encoding method will quickly switch between multiple frequencies, regardless of the specific duration of each frequency, thus completing data transmission in a shorter time. Due to the fast frequency switching, it reduces the impact of external interference and improves the stability and efficiency of data transmission.

The difference in transient information between modal transitions comes from the mechanical properties of the sphere-string structure. The frequency duration T can be further shortened by studying the specific parameters related to the sphere-string structure through simulation.

Maximum frequency switching speed（Hz/s)	Code
[30,40]	1
[60,80]	2
[40,50]	3
[-40,-30]	4
[-80,-70]	5
[-50,-40]	6

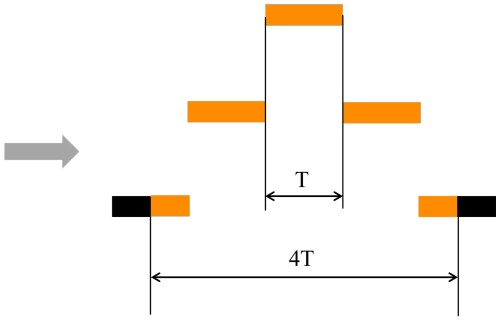

Figure 2: Transient information encoding method diagram

4 Conclusions

This study utilizes the maximum frequency switching speed between modal transformations of the sphere-string structure as the encoding information for the mechanical antenna. Compared to the frequency-time encoding method, the communication efficiency is increased by more than three times. In subsequent research, variables related to transient information will be identified through mechanical simulation to reveal the mechanism of modal transformation.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. Kemp, M. A., Franzi, M., Haase, A., Jongewaard, E., Whittaker, M. T. et al. (2019). A high Q piezoelectric resonator as a portable VLF transmitter. *Nature Communications, 10,* 1715.
2. Chu, L. J. (1948). Physical limitations of omni-directional antennas. *Journal of Applied Physics, 19(12),* 1163–1175.
3. Cui, Y., Wang, C., Song, X., Wu, M., Zhang, Q. Y. et al. (2023). A survey of mechanical antennas applied for low-frequency transmitting. *iScience, 26(1),* 105832.
4. Yao, X. Y., Liu, T., Wang, H. L., Yuan, W. F. (2025). Extremely low frequency communication using signal modulation of sphere-string structured mechanical antenna. *Journal of Applied Physics, 137 (6),* 064901.