Analysis of the Effect of Wave Phase Modification on Binary Representation: Simulation Using Phet Wave Interference

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ABSTRACT
The aim of this study is to analyze the effect of wave phase modification using PhET Wave Interference simulation on binary representation. By adjusting the phase difference between two wave sources, the resulting interference pattern can be analyzed to represent binary data bits (0 and 1). The method used is virtual observation of pattern changes due to variations in amplitude, frequency, and distance between sources. The results show that a phase change of 0° results in destructive interference (bit 0), while a 180° change results in constructive interference (bit 1). Amplitude and frequency modifications also affect the clarity and stability of the interference pattern. This simulation proves that waves can be used to carry and store binary information by modifying the wave phase.

ABSTRAK

Penelitian bertujuan untuk menganalisis pengaruh modifikasi fase gelombang dengan menggunakan simulasi PhET Wave Interference terhadap representasi biner. Dengan mengatur perbedaan fase antara dua sumber gelombang, pola interferensi yang terbentuk dapat dianalisis untuk merepresentasikan bit data biner (0 dan 1). Metode yang digunakan adalah observasi virtual terhadap perubahan pola akibat variasi amplitudo, frekuensi, dan jarak antar sumber. Hasilnya menunjukkan bahwa perubahan fase 0° menghasilkan interferensi destruktif (bit 0), sedangkan 180° menghasilkan interferensi konstruktif (bit 1).Modifikasi amplitudo dan frekuensi juga berpengaruh terhadap kejelasan dan kestabilan pola interferensi. Simulasi ini membuktikan bahwa gelombang dapat dimanfaatkan untuk membawa dan menyimpan informasi biner dengan memodifikasi fase gelombang.

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KEYWORDS
Wave Phase, Interference, Binary, Modulation, PhET Simulation

INTRODUCTION

Technology still faces many significant challenges, even though it has developed rapidly. One of these is the need for secure and undetectable data transmission. According to Wisman (2017), threats to communication security, such as signal interference or noise, continue to evolve with technological advancements. The development of communication and information processing technology has spurred the emergence of various new methods in data encryption and delivery. One of the fundamental concepts in this technology is binary representation. Therefore, innovative solutions are needed to enhance data transmission security and reliability, one of which is by utilizing wave properties as a medium for binary representation. (Ramadhani & Nasution, 2024). One of the intriguing physical phenomena in Physics is waves and their dynamics. The fields of mechanical engineering, civil engineering, electronics, aeronautics, geosciences, and acoustics are just a few that greatly require an understanding of wave physics. Waves are everywhere in our lives; consciously or not, they are fundamentally wave-based. Sound, light, television, microwaves, the internet, computers, mobile phones, and many others are merely phenomena that utilize waves. (M. Ishaq, 2003).

A wave is a propagation of vibrational energy that travels through a medium or without a medium. Based on their medium, waves are classified into two types: mechanical waves and electromagnetic waves. Mechanical waves are waves whose propagation requires an intermediary medium, while electromagnetic waves are waves whose propagation does not require a medium. Based on their propagation, waves are divided into two types: transverse waves and longitudinal waves. Transverse waves are waves whose propagation is parallel to their vibration and medium, while longitudinal waves are waves whose propagation is parallel to their vibration and medium. Waves, as vibrations propagating through or without a medium, play a crucial role in various aspects of life. (Nadia *et al.*, 2023). Waves, as vibrations propagating through or without a medium, play a crucial role in various aspects of life. Waves can be classified into transverse and longitudinal based on their direction of propagation. Wave characteristics such as

amplitude, frequency, phase, propagation speed, and wavelength (Farida et al., 2020) enable waves to be used as information carriers. One unique property of waves is interference, which is the superposition of two or more waves that results in a new wave. This interference can be constructive (mutually reinforcing) or destructive (mutually weakening) (Nurdiansah et al., 2020).

Wave phase becomes an interesting aspect because it can be modified to change interference patterns without affecting the total wave energy. This phase modification can be utilized for binary representation, where phase differences such as 0° and 180° can represent data bits (0 and 1). This technique is known as wave steganography, which is the process of hiding secret information within wave components (Andika & Darwis, 2020).

To deeply understand this concept, computer-based simulation becomes an effective tool. One widely used interactive simulation is PhET Wave Interference, which allows users to manipulate wave parameters such as frequency, wavelength, and phase difference. By using this simulation, users can observe how changes in phase affect the resulting interference pattern (Hasanah & Wasis, 2021).

A suitable virtual laboratory to use is PhET Simulation. PhET is a series of interactive simulations that are highly beneficial in integrating computer technology into learning or experiments. This medium emphasizes the connection between real-life phenomena and underlying science, supports interactive and constructivist approaches, provides feedback, and offers a creative learning space. PhET Simulation is very useful for enhancing knowledge and skills in learning. PhET Simulation is very useful for enhancing knowledge and skills in learning. Utilizing the principle of wave interference in the context of information technology. By modifying the wave phase, information can be efficiently embedded through constructive and destructive interference patterns, creating an innovative communication method. By modifying the wave phase, information can be efficiently embedded through constructive and destructive interference patterns, creating an innovative communication method. The PhET Wave Interference simulation provides an interactive platform to dynamically visualize and analyze this phenomenon, analyzing parameters such as wavelength, amplitude, and phase for binary representation.

The PhET Wave Interference simulation facilitates a deep understanding of how wave phase modification works for binary representation. In this project, virtual experiments were conducted by changing wave phase parameters to observe changes in the resulting interference patterns. The simulation results show that binary data is obtained by changing the wave phase difference, which is then translated through the interference pattern on the detector screen. This approach not only enriches the theoretical understanding of wave interference but also opens opportunities for the development of practical applications in information security and wireless communication, with the interactive visualization support provided by PhET. (Purba, N. O. A. (2025).

Based on this background, this project aims to represent binary bits through wave phase manipulation using the PhET Wave Interference simulation. By adjusting the phase difference between two wave sources, the resulting interference pattern is analyzed to represent binary data. This approach is expected to provide a more applicable understanding of the working principles of phase modulation and how wave interference can be used as the basis for wave-based communication.

METHODS

The research method used in this project is a qualitative approach with descriptive qualitative methods. The data collection technique uses a case study using PhET software. This project uses PhET simulations to gain a deeper understanding of binary representations through wave phase modification. The following is the project procedure: The procedure for this project begins with the flowchart created. It begins by opening the PhET simulation application. Next, search for and select the wave interference simulation. Afterward, the initial variables required to run the simulation are declared and input. The independent variables used in this simulation are frequency and amplitude. These variables are then adjusted from their initial values until they reach the desired maximum value. The experimental results are then analyzed by observing the phase difference between the two waves. If the phase difference is 180 degrees, the phase difference is converted to 1 bit. If not, the phase difference is checked to see if it is 0 degrees. If so, the value is converted to 0 bit. This process continues until the desired combination of variables is achieved. After all steps are completed, the binary representations at each phase are analyzed, and the results are recorded in a report to summarize the exploration.

The data collection method used in this project was observation and documentation of PhET simulations of interference waves by observing the phase changes of waves modified in frequency and amplitude. Phase changes, such as 0° and 180°, can represent binary information in the form of bits 0 and 1.

The following is a flowchart of this project:

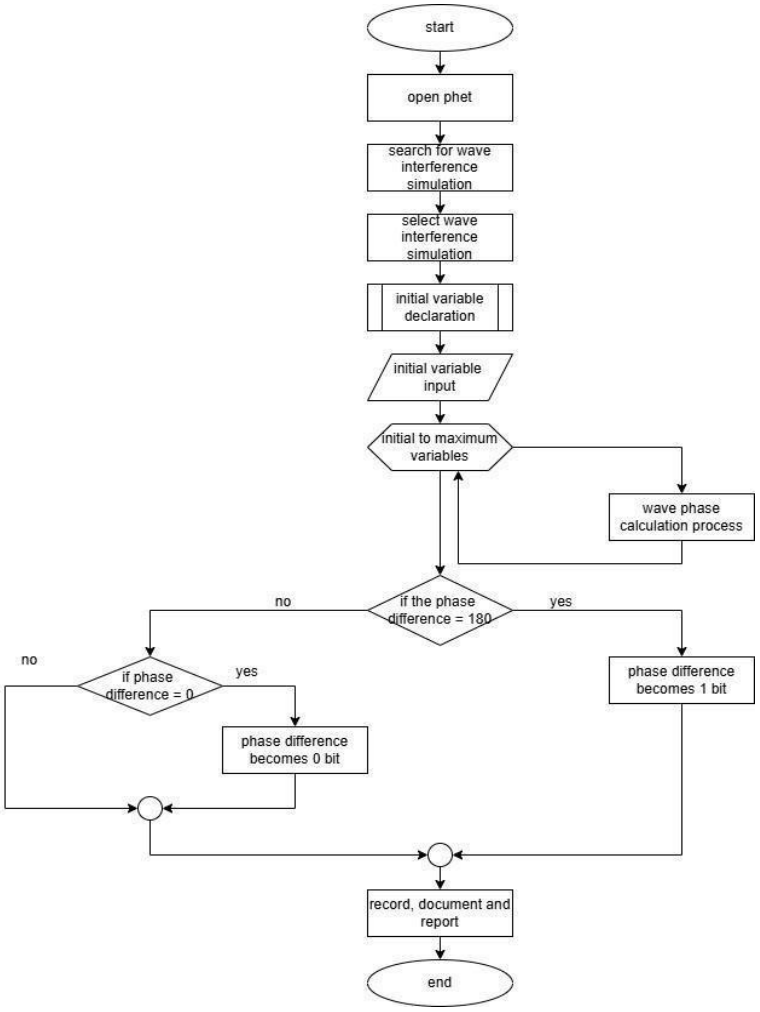

Figure 1. Flowchart

RESULTS AND DISCUSSIONS

Experimental Result Data

1. Amplitude modulation
   Frequency = 6000 Hz; Separation distance = 200 cm

Table 1. Binary of Amplitude modulation

λ	Amplitude 1	Amplitude 5	Amplitude 10
50	0	1	1
100	0	1	1
150	0	1	1
200	0	1	1
250	0	1	1
300	0	1	1
350	0	1	1
400	0	1	1
450	0	1	1
500	0	0	1

2. Frequency Modulation
   Amplitude = 5 cm; Separation = 200 cm

Table 2. Binary of Frequency Modulation

λ (cm)	**Fequency 1000 Hz**	**Fequency 6000 Hz**	**Fequency 11000 Hz**
50	1	1	1
100	1	1	1
150	1	1	0
200	1	1	1
250	0	1	0
300	1	0	1
350	1	0	0
400	1	0	0
450	0	1	1
500	1	1	0

3. Source Separation
   Amplitude = 5 cm ; Frequency = 6000 Hz

Table 3. Binary of Source Separation

λ (cm)	**100 cm**	**200 cm**	**300 cm**	**400 cm**
50	1	1	0	0
100	1	1	1	1
150	1	1	1	1
200	1	1	1	1
250	0	0	1	0
300	0	0	0	1
350	0	0	0	1
400	0	0	0	1
450	0	1	1	0
500	0	0	0	0

Analysis and Discussion

This research is entitled "Analysis of the Effect of Wave Phase Modification on Binary Representation: Simulation Using Phet Wave Interference". This research was conducted to convert waves into binary data, namely bit 1 and bit 0. Binary data is obtained from modifying the wave phase with amplitude modulation and phase modulation. Amplitude modulation sets the frequency value at 6000 Hz and changes the amplitude value into 3 variations. The amplitude variations in this study are 1 cm, 5 cm and 10 cm. As well as, frequency modulation by setting the amplitude value at 5 cm and changing the frequency value into 3 variations, namely 1000 Hz, 6000 Hz and 11,000 Hz. Bit 1 represents constructive interference. Meanwhile, bit 0 represents destructive interference.

Based on the Amplitude Modulation Experiment, a relationship was obtained between the bit number (binary) and the intensity pattern identified at each wavelength (λ), The amplitude A of a wave scales the intensity ($I \propto A^2$). Constructive conditions produce maximum intensity, while destructive conditions produce minimum intensity. Bit 1 (constructive) is given if I > I threshold, and bit 0 (destructive) if I ≤ I threshold. There are 3 amplitude variants identified by bit numbers (binary):

1. Amplitude 1
   At a low amplitude of 1, the intensity is so low that the dark (destructive) pattern is difficult to observe at all observation points, resulting in a series of 0 bits in all measurements (50–500cm). This is in line with the expectation

that the amplitude is too small to reach the intensity threshold.

2. Amplitude 5

   Almost all points give bit 1, except at 500 cm (bit 0). This is because the wavelength traveled when reaching 500 cm produces I ≤ I threshold

3. Amplitude 10

   At a high amplitude of 10, the intensity is high enough for a bright (constructive) pattern to be easily observed, resulting in a series of 1 bits in all measurements (50–500 cm). This is in line with the expectation that high amplitudes will exceed the intensity threshold (I > I threshold).

   In Separation, a relationship is obtained between the number of bits (binary) and the intensity pattern identified at each wavelength (λ). In the source separation experiment with an amplitude of 5 cm and a frequency of 6000 Hz, the binary bit pattern (constructive = 1, destructive = 0) observed at wavelengths λ from 50 cm to 500 cm changes systematically when the distance between sources (d) is varied between 100 cm, 200 cm, 300 cm, and 400 cm. For small wavelengths (λ = 50cm), the two sources are separated (bit = 1) at relatively narrow distances (100cm and 200cm), while at larger distances (300cm and 400cm) the system is unable to distinguish the two sources where the signals are mixed so that the bit becomes 0. When λ increases to 100cm to 200cm, all distances between sources (100, 200, 300, 400cm) show bit = 1, indicating a flexible wavelength range

CONCLUSIONS

Based on the results of the analysis and simulation experiments using PhET Wave Interference, it can be concluded that: Wave phase modification has a significant effect on the interference pattern formed. With a phase change of 0° and 180°, the interference formed can represent binary data in the form of bit 0 and bit 1. Amplitude and frequency modulation techniques successfully show constructive and destructive interference patterns, which are encoded as bit 1 and bit 0, respectively. The higher the amplitude, the greater the wave intensity, so that the appearance of interference increases. Frequency variation experiments show that the higher the frequency, the shorter the wavelength and the denser the interference pattern, which affects the accuracy of binary data representation. Experiments varying the distance between sources (separation) show that too large a distance causes interference in the readability of the interference pattern, thereby reducing the clarity of binary data representation. This simulation proves that binary data representation using waves can be done effectively with phase manipulation, and opens up the potential for wave-based applications.

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