Real Remote Experiment with Embedded Synchronized Simulation "Remote Wave Laboratory"

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Abstract—The paper describes a new remote experiment in REMLABNET as "Remote Wave Laboratory" constructed on the ISES (Internet School Experimental System). The remote experiment contributes to understanding of concepts of harmonic waves, their parameters (amplitude, frequency and period, and phase velocity) and dependence of the instantaneous phase on time and path covered. Also it serves for the measurements and understanding of the concept of the phase sensitive interference and the superposition of parallel/perpendicular waves.

Keywords—to ISES, remote wave laboratory, embedded multiparameter simulation, wave phenomena, parameters of waves, interference, superposition

1 Introduction

Waves and their phase sensitive interference and superposition are important phenomena constituting a major problem in students' teaching of waves and optics, due to the necessary students' imagination. Then, the phenomena of interference of waves and their superposition are difficult to understand. The proposed "Remote Wave Laboratory" is aimed at real measurements of the phase and the most frequent phenomena of phase-sensitive wave superposition on real physical instrumentation with multiple use and applications. As a teaching tool for better understanding of real measurements serves the embedded real multiparameter simulation of the observed phenomena introduced for the first time in our remote experiments.

2 Purpose or goal

The whole system of the remote experiment (RE) "Remote Wave Laboratory" is conceived to enable demonstrating the basic concepts of wave phenomena, as:

— The concept of the basic parameters of harmonic waves - the amplitude, the frequency, the period, the initial phase, the phase velocity and the wavelength,

— The concept of the instantaneous phase (corroborated with our electronic phase laboratory) as the function of the elapsed time and the path covered by the wave (in relation to two periodicities of waves - in time and in space),
— The concept of the phase sensitive interference and the superposition of parallel/perpendicular waves.

3   Approach and schematic arrangement

3.1   Theory of wave laboratory

Let us suppose the signal detected by both acoustic detectors is $u_1 = a\sin(\omega t)$ and $u_2 = a\sin(\omega t + \Delta\varphi)$.

- **Parallel interference** of both signals gives in general

$$x_1 + x_2 = a\sin(\omega t) + a\sin(\omega t + \Delta\varphi) = A\sin(\omega t + \Delta\phi), (1)$$

  where the amplitude *A* and the initial phase $\Delta\phi$ of the resulting signal is

  $$A = a\sqrt{2(1 + \cos(\Delta\varphi))}, (2)$$

  $$tg(\Delta\phi) = \frac{\sin(\Delta\varphi)}{1+\cos(\Delta\varphi)}. (3)$$

- **Perpendicular superposition** of both signals gives $x = a\sin(\omega t)$ and $y = a\sin(\omega t + \Delta\varphi + \pi/2)$ gives in general

$$y^2 - 2xy\cos(\Delta\varphi) + x^2 = a^2\sin(\Delta\varphi)^2, (4)$$

  which reduces in particular cases $\Delta\varphi = 0$ and $\pi/2$ into the straight line and circle, respectively, in other cases of $\Delta\varphi$ gives an ellipse.

- **Phase measurements -** it is then possible to determine the phase shift of both signals (waves) $\Delta\varphi$ from the position of the ellipse as shown Fig. 1.
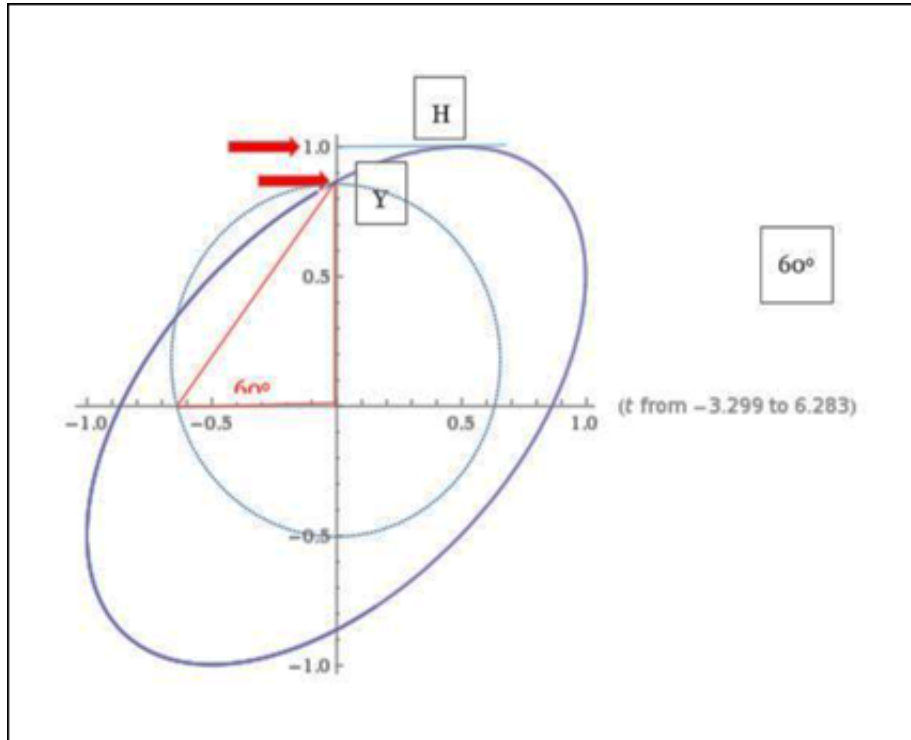
  $$\Delta\varphi = arcsin\left(\frac{Y}{H}\right) (5)$$

Fig. 1. Scheme for the phase shift Δφ of two waves determination using eq. (4) and (5)

3.2 Students' results in computer oriented hands-on laboratory

Computer oriented hands-on laboratory exercise on acoustic waves has been for considerable time the part of students' laboratory. Its arrangement is similar as that in Fig. 3, with positioning of the sound detector manually. The students' results are in Fig. 2, where a) depicts the phase shift dependence of both signals from detectors Δφ on the wave path difference of both waves Δx for wavelength λ = 35.3 cm, and in b)-d) are the superpositions of two waves' signals for phase shifts Δφ = 0 rad b), Δφ = π/2 rad and c) Δφ = π rad d). The upper panel shows the signals of both the sound waves, the middle panel the phase-sensitive superposition - Lissajous figures (for perpendicular waves) and the bottom panel shows the phase-sensitive interference signal (for parallel waves).

3.3 "Remote Wave laboratory"

The arrangement of the remote experiment (RE) "Remote Wave Laboratory" is in Fig. 3 both in schematical and real experimental arrangement. The acoustic wave source generates the planar wave, which is detected by two detectors, one of them is movable by the motor drive in a controlled way, producing the phase shift Δφ of both
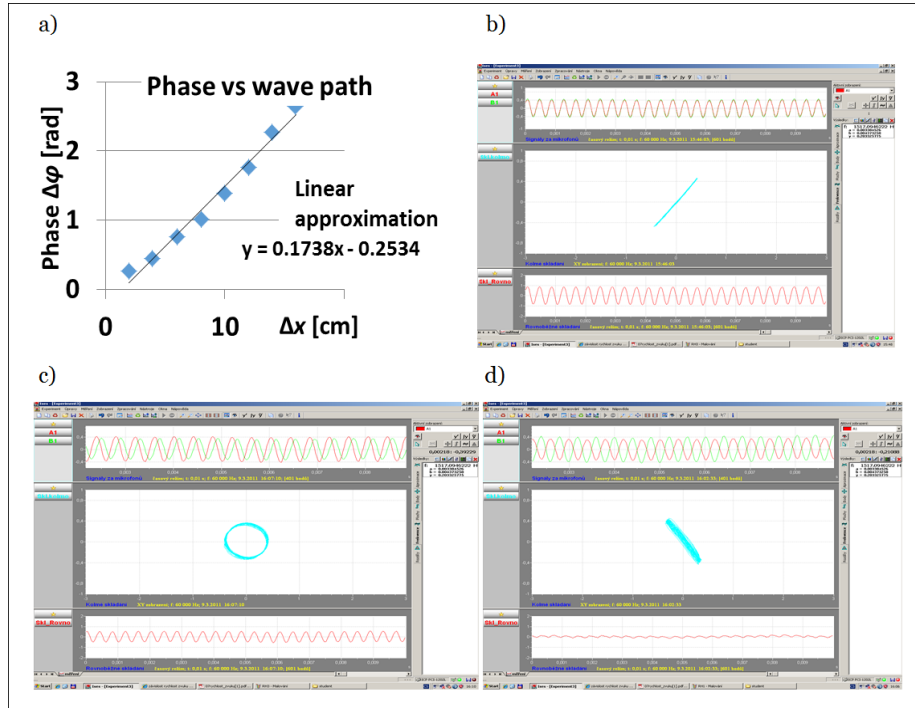
Fig. 2. Examples of student's work on hands - on experiment a) Phase shift $\Delta\varphi$ dependence on the difference of the wave path Δx, b)-d) Superposition of two waves for phase shift $\Delta\varphi=0$ rad b), $\Delta\varphi= \pi/2$ rad c), $\Delta\varphi= \pi$ rad d), all for the wavelength $\lambda = 35.3$ cm; the upper panel shows signal of both waves, the middle panel phase-sensitive superposition-Lissajous figures (for perpendicular waves) and bottom panel phase-sensitive interference signal (for parallel waves)

coherent signals, corresponding to the detectors distance Δx. Both signals are phase-sensitively added/superimposed in parallel/perpendicular directions.

The ISES USB module with the controlling PC controls the remote experiment serving of both RE and embedded simulation (ES) control. The system is built on the Internet School Experimental System (ISES) components [1]. The whole arrangement is placed on the optical bench and it consists of the loudspeaker as the wave source and two miniature microphones as the signal detectors, one of them is movable by the step drive. Both signals are displayed, together with their phase-sensitive interference signal (for parallel, linearly polarized progressive waves) and phase-sensitive super-position Lissajous figures (for perpendicular, linearly polarized progressive waves) with the corresponding data outputs for data processing (see Fig. 2). The .psc file controlling program and the web page were built using ISES environment Easy Remote ISES (ER ISES) for compiling the control RE programs [1].
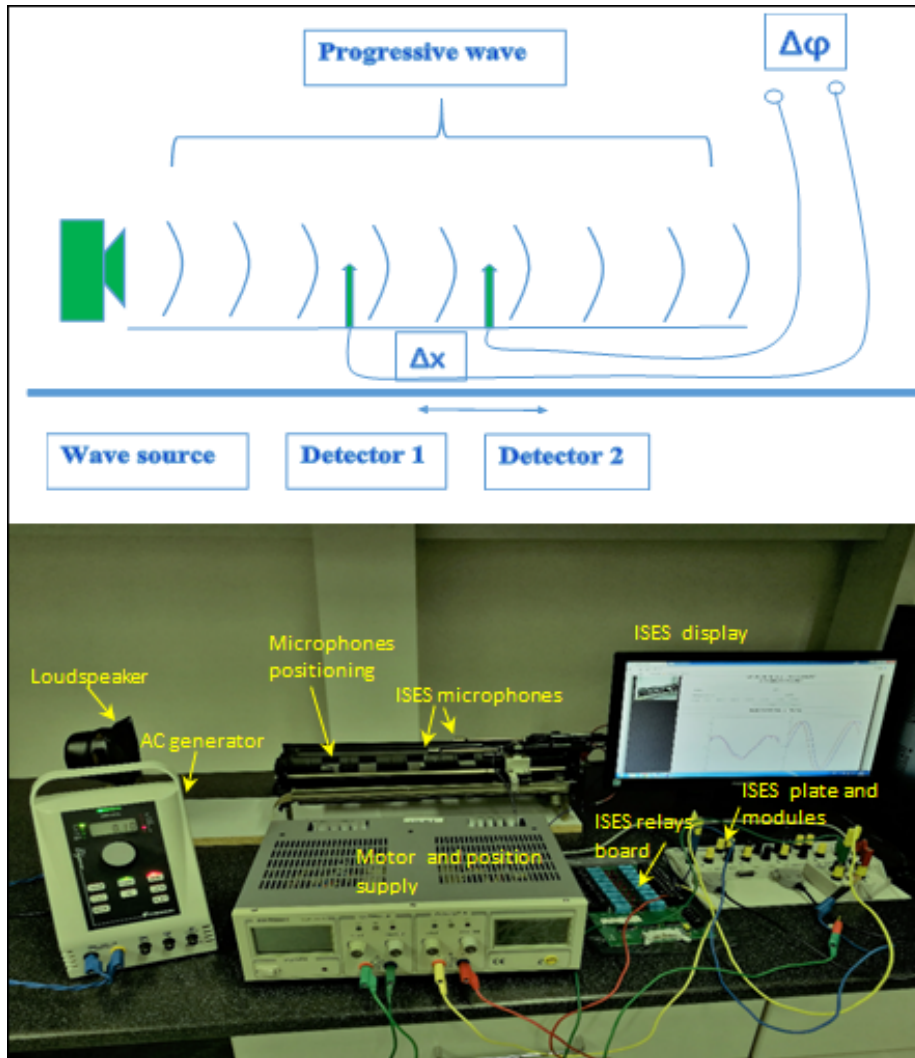
Fig. 3. Schematic arrangement (upper panel) and the real RE "Remote Wave Laboratory" (lower panel) with the loudspeaker as the acoustic wave source, two acoustic detectors 1 and 2 and the driving motor for moving detector 2, producing the phase shift Δφ of both signals, corresponding to the detectors´ distance Δx

3.4 Embedded simulation of the wave laboratory

In Fig. 4 is the web page of RE "Remote Wave Laboratory" (from Fig.3) with the measured data output (left) and the output of the embedded simulation (right).

As the part of the solution of embedded simulations in our ISES RE we used the mathematical solver built in RE Measureserver unit and its .psc file. The solver provides solving of a wide range of arithmetic operations and solves ordinary differential

equations [4]. The example of the use for the response of the RLC circuit to voltage perturbation is shown in Fig. 5 [2], here was used for simple plotting of calculated quantities according to eqs. (1-4).

The Measureserver unit is a significant software part of the ISES RE concept. It is the processing and communicating server located between the physical hardware and connected clients. The Measureserver core is designed as an advanced finite-state machine to setup and process the logical instructions solving prescribed activities. Its functioning is based on the control program that comes from the .psc file loaded to the Measureserver before its startup.

When the client starts RE, the Measureserver begins the communication with ISES HW. Then the RE is ready to perform all the required measurements according to the web page instructions given by the client. Then, the Measureserver obtains experimental data from the ISES modules (meters, sensors and probes) and transports them again on the client's web page for the analysis [3].

Fig. 4. Example of the view of the RE web page "Remote Wave Laboratory", measured data, (left) and simulation of the observed phenomenon (right); from upper graph: both signals-perpendicular superposition- interpherence; the position of the movable detector is visible in the live stream
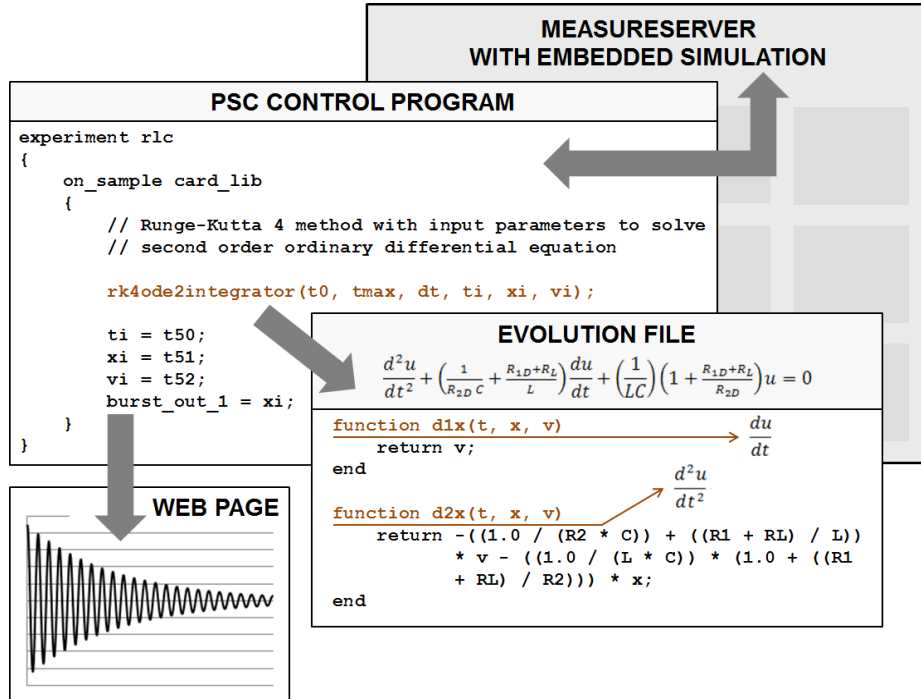
Fig. 5. The general mathematical unit for ISES remote experiments enabling both arithmetical operations and differential equations solutions

The embedded ES works in a similar way, replacing the ISES module by the mathematical solver and providing the data for graphical comparison with the measured data. The difficult problem was the synchronization of both measured and simulated data into one time dependent graphical representation to study the role of model parameters on the resulting signals.

4 Conclusions

The remote environment "Remote Wave Laboratory" provides the following knowledge from waves:

— Phase of the wave as a function of the covered distance (with respect to the reference signal and its linearity),
— To examine parameters of the wave - the phase velocity and the wavelength in a medium, the amplitude, the frequency and the period of the wave,
— To examine the concept of the coherence of two acoustic waves,
— To show the phase sensitive interference of two parallel waves and find the conditions for extremes,

— To show the phase sensitive superposition of two perpendicular waves and to find the phase shift and amplitude to the reference wave,
— To find the integer quotient of frequencies of an unknown waves.

5 Acknowledgment

6 References

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[4] Inspiration of prof. F. Esquembre in solver compiling is appreciated.

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