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A COMPUTER AIDED STUDY OF TWO PERPENDICULAR HARMONIC OSCILLATIONS OF THE SAME FREQUENCY

BY

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Abstract. The goal of this paper is the study of two perpendicular harmonic oscillations of the same frequency using the HTML5 technology and the JavaScript language. With the aid of these technologies we developed the physics simulation for this experimental work. An experimental application is the determination of the speed of sound. This application is the subject of one of the laboratory classes of the Physics I course that is designated to the second semester of the first year at the Faculty of Civil Engineering and Building Services of “Gheorghe Asachi” Technical University of Iași. Using HTML5 and JavaScript language the students will be more motivated to work faster and a deeper understanding of the study of oscillatory motion will be developed. Moreover, the Matlab program is used for making the graphical representations.

Keywords: two perpendicular harmonic oscillations of the same frequency; Civil Engineering; HTML5; JavaScript; Matlab; simulations; physics phenomena.

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1. Introduction

Computational instruments and simulations are more and more widely used and many teachers deal with them to improve the teaching-learning process (<http://phet.colorado.edu>; <http://wildcat.phys.northwestern.edu>; www.myphysicslab.com; <http://virllab.virginia.edu>; <http://www.java.com/en>; Covatariu & Covatariu, 2008).

Traditionally, working in the physics laboratory means to work in a controlled environment where the information can be introduced sequentially by using the laboratory equipment. The target for each lab is to pick up some experimental data and compute the value of some physical required quantities together with making graphical representations where necessary. An alternative to experimental works are the physics simulations. Along the years, our experience in using computational instruments for improving our Physics courses and laboratories pointed out that traditional methods in teaching-learning Physics unified with computer simulations can be an important tool that allows students to explore modern Physics and better understand the physical phenomena and engineering studies (Smith & Pollard, 1986; Andaloro *et al.*, 1991; Wisman & Forinash, 2008; Gould *et al.*, 2007).

In this way, the students will improve their learning process and obtain good marks at exams. In the last years we used to work with programs like Adobe Flash (adobe.com/products/flash), Maple, Mathematica and Matlab (www.maplesoft.com; www.wolfram.com; www.mathworks.com). Also, in the future, we want to extend our course to include more physics phenomena and experiments based on simulations packages.

Our Physics 1 course runs one semester and is a 3 credits course that consists in lecture combined with advanced laboratories that provide the description of the most important physics methods with applications in Civil Engineering. During the laboratories, students study the two perpendicular harmonic oscillations of the same frequency, damped oscillations, standing waves, electromagnetic waves and some optical phenomena such as light interference and diffraction.

In this paper, as an example of physics simulation the authors use HTML5 and the JavaScript language (<https://developer.mozilla.org/en-US/docs/Web/Guide/HTML/HTML5>; <https://www.javascript.com>) for the study of two perpendicular harmonic oscillations of the same frequency. An application of this physics laboratory is the evaluation of the speed of sound. Also, for plotting the experimental data the Matlab program can be used.

2. Two Perpendicular Harmonic Oscillations of the Same Frequency

One of the two hours physics laboratories of the second semester at the Faculty of Civil Engineering and Building Services of “Gheorghe Asachi” Technical University is focused on the study of two perpendicular harmonic oscillations of the same frequency (Neagu *et al.*, 2001). Together with the experimental method we also use the physics simulation that is elaborated using the HTML5 technology and the JavaScript language. The experiment conveys how the speed of sound can be calculated using two perpendicular harmonic oscillations of the same frequency.

In the next we present the study of two perpendicular harmonic oscillations of the same frequency. Let us consider that a material point simultaneously undergoes two harmonic oscillations, one along Ox , the other along Oy :

$$x = A \sin \omega t, \quad (1)$$

$$y = B \sin(\omega t + \varphi). \quad (2)$$

In order to obtain the trajectory equation, we leave out the time from the relations (1) and (2).

As a result, relation (1) becomes:

$$\sin \omega t = \frac{x}{A} \Rightarrow \cos \omega t = \sqrt{1 - \sin^2 \omega t} = \sqrt{1 - \frac{x^2}{A^2}}. \quad (3)$$

Combining (1) and (2) one obtains:

$$y = B \sin \omega t \cos \varphi + B \cos \omega t \sin \varphi,$$

$$y = B \frac{x}{A} \cos \varphi + B \sqrt{1 - \frac{x^2}{A^2}} \sin \varphi,$$

$$y - B \frac{x}{A} \cos \varphi = B \sqrt{1 - \frac{x^2}{A^2}} \sin \varphi. \quad (4)$$

By squaring this relation, one gets:

$$\frac{y^2}{B^2} + \frac{x^2}{A^2} - \frac{2xy}{AB} \cos \varphi = \sin^2 \varphi. \quad (5)$$

The trajectory is an ellipse. The consecutive motion is an elliptical periodical motion (Fig. 1).

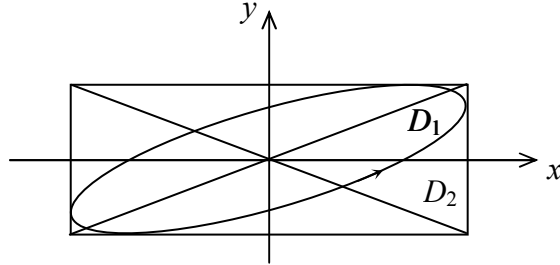


Fig. 1 – The elliptical periodical motion.

Particular Cases

By denoting with $\varphi = \varphi_2 - \varphi_1$ the phase difference between the oscillations we have the following particular cases.

Case 1) If $\varphi_2 - \varphi_1 = 2k\pi$, from relation (5) it follows:

$$\frac{y^2}{B^2} + \frac{x^2}{A^2} - \frac{2xy}{AB} = 0 \Rightarrow \frac{x}{A} = \frac{y}{B}. \quad (6)$$

The consecutive motion is a harmonic oscillatory motion along the line D_1 of slope $\frac{B}{A}$ that represents the first diagonal from the amplitude rectangular.

This is the case of linear polarization.

Case 2) If $\varphi_2 - \varphi_1 = (2k + 1)\pi$, from relation (5) one gets:

$$\frac{x}{A} = -\frac{y}{B}. \quad (7)$$

The consecutive motion is a harmonic oscillatory motion along the line D_2 of slope $-\frac{B}{A}$. Also, one gets linear polarization.

Case 3) If $\varphi_2 - \varphi_1 = (2k + 1)\pi/2$, from relation (5) we have:

$$\frac{y^2}{B^2} + \frac{x^2}{A^2} = 1. \quad (8)$$

The motion is periodical on an ellipse around an axis. For $\varphi_2 - \varphi_1 = \frac{\pi}{2}$ the motion is clockwise and we have elliptical polarization (right-handed polarization) and for $\varphi_2 - \varphi_1 = 3\pi/2$ the motion is counter-clockwise, with elliptical polarization (left-handed polarization).

A particular case is $A = B$ and the ellipse becomes a circle:

$$x^2 + y^2 = A^2. \quad (9)$$

In this case we have circular polarization.

Reciprocally, any circular periodical motion can be decomposed in two cross harmonic oscillations, of similar ν and A , and with the phase difference $(2k + 1)\pi/2$.

The laboratory equipment consists of electrical connections, signal (frequency) generator, oscilloscope, microphone, speakerphone, a mobile tube and a fixed tube. The tubes are filled with air.

An application of this physics lab is the evaluation of the speed of sound. By keeping a fixed value of the frequency ν at the generator the students will vary the distance by moving the mobile tube and will mark the positions where they obtain a difference of phase equals to π and 2π , respectively (in these cases they collect experimental data between the lines D_1 and D_2 , and between the lines D_1 , D_2 and again D_1 , respectively). In this way the students are able to check experimentally the relationship between the speed of sound and the variation of the length of the air column and frequency ν at the generator.

They calculate the speed of sound with the relation

$$v = 2(l_2 - l_1)\nu, \quad (10)$$

for a difference of phase equal to π . For the difference of phase equal to 2π they use the relation

$$v = (l_2 - l_1)\nu. \quad (11)$$

An important task is to take and record measurements for at least ten different frequencies.

If the case of different frequencies the consecutive trajectory has a more complicated form. If the frequency ratio is a rational number, $\nu_1 / \nu_2 = n_1 / n_2$, $n_1, n_2 \in \mathbb{N}$ what we obtain are closed trajectories, called Lissajous figures.

In the physics laboratory the experimental data are collected using the laboratory equipment that has been previously presented. In the case of the physics simulation the Fig. 3 includes a similar configuration detailed bellow.

3. HTML5 and JavaScript Simulation for Two Perpendicular Harmonic Oscillations of the Same Frequency. Plotting the Experimental Data

Working in a traditionally physics lab the students need to complete all the activities for reaching the goal of the lab. This consists in picking up by hand the experimental data, make calculations and graphs. A step along the line of improving the activities in the physics laboratories is the use of physics simulations. A physics simulation makes experimenting and plotting faster and

fosters commitment and a feeling of involvement to the advantage of learning. Moreover, a physics simulation has a positive impact on learning process and also an important educational purpose, to raise curiosity for the used computational resources and for the physical phenomena under study.

We have implemented the HTML5 technology and the JavaScript language in the Physics laboratories by developing the simulation for the study of two perpendicular harmonic oscillations of the same frequency. Moreover, the experiment allows students to calculate the speed of sound.

The graphical representations are obtained using the Matlab program. Engineers and scientists worldwide use the Matlab program because its many capabilities like numeric computation, data analysis and visualization, programming and algorithm development, graphics, control system design and analysis.

In the following we present the physics simulation for the study of two perpendicular harmonic oscillations of the same frequency and the commands used for plotting the experimental data. For plotting data the Matlab program is used and as an example the graphs of the consecutive motion are showed in the Fig. 2. We also show a sequence of code in the Matlab program which has been used for plotting the trajectories of the oscillatory motion, as follows.

```
% waves plot for
% x=A*sin(omega*t)
% y=B*sin(omega*t+phi)
A = 4;
omega = 2;
B = 6;
phi = 0;
t = 1:0.05:10
x = A*sin(omega*t)
y = B*sin(omega*t+phi*pi)
figure()
plot(x,y)
axis([-4 4 -6 6])
title([' {fontname{symbol}j}', ' = ', char(num2str(b3a))])
drawaxis(gca, 'x', 0, 'movelabel', 1, 'y', 0, 'movelabel', 1)
```

We notice that the students also use the Matlab program for plotting the picked up experimental data.

The most frequently solutions used by an animation into a browser are flash animations based on Adobe and HTML5 technology that are programming languages adopted by the World Wide Web Consortium (W3C). Each method has advantages and disadvantages.

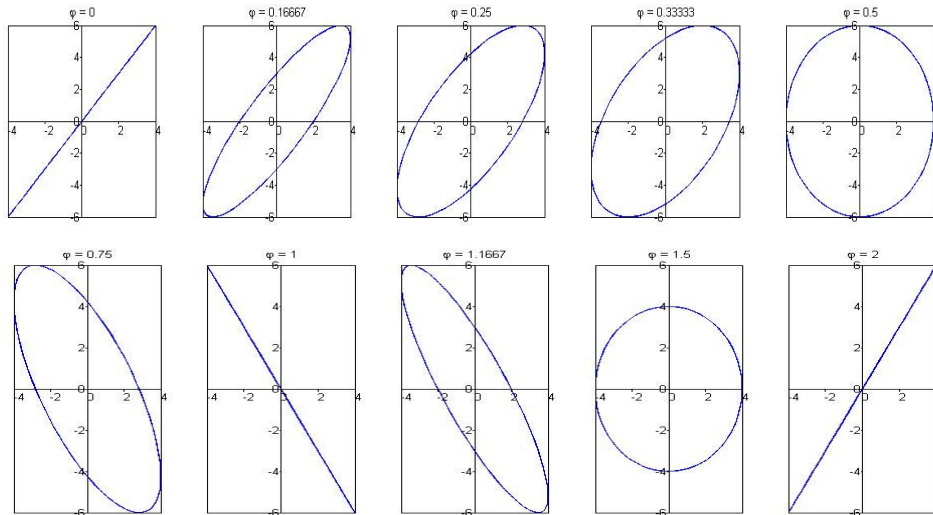


Fig. 2 – Graphs of the consecutive motion by using the Matlab code.

The advantage of a plugin such as Adobe Flash Player is that the animation is not dependent on the browser version. The disadvantage is that it is an exclusive technology and the company that owns the software can decide how it wants in its evolution. This is an inconvenience because the applications cannot run on certain operating systems or mobile devices.

HTML5 is a technology that uses open standards agreed by the international organizations. Additional plugins are not required for any application that runs in the browser natively. However, this technology has some difficulties because the implementation of various works in different browsers is not standardized and developers must solve various compatibility issues.

To achieve virtual animation of this experiment HTML5 was chosen.

A static image of equipment's was reproduced in the Fig. 3 by the virtual application that consists of electrical connections, signal (frequency) generator, oscilloscope, microphone, speakerphone, a mobile tube and a fixed tube. The static image presents the major advantage of being easy to use into a web application.

There are 3 HTML canvas elements of the static image whose charts were realized. Two are used for measuring instruments and the last one for sound animation on the microphone – speakerphone layout. Besides all of these elements, different control tools are used as: on-off switches, amplitude and frequency controllers and simulated microphone that can be horizontally moved using the mouse.

Moreover, external JavaScript libraries were used to achieve this virtual application as follows:

- JQuery.js and jquery-ui.js user interface were used to access the webpage and may succeed the functionality of the microphone movements;
- Alertify.js and tooltipster.js have an aesthetic role. Also, were used to show the error messages in case of browser incompatibility (alertify.js) or to display a help message balloon (tooltipster.js);
- Modernizr.js is used to detect the browser compatibility of the core technology;
- Require.js is used to organize the JavaScript code.

All listed libraries are free for use and adaptation. Furthermore, specific code sequences were realized in different files. Below, the functionality is briefly listed:

- Graph.js implements specific methods to achieve the graphical representation. Basic functions are used in HTML5 to draw a canvas element (MoveTo, lineTo etc.). To obtain the appearance of Lissajous figures the $x_{liss}(t)$ and $y_{liss}(t)$ mathematical functions were used. The results obtained by $x_{liss}(t)$ and $y_{liss}(t)$, respectively are transmitted to *drawParametricCurve* function that is defined in the *graph.js* module beside with other required plotting procedures.

```
Graph.prototype.drawParametricCurve = function(xeq, yeq, color, thickness) {
    var context = this.context;
    context.save();
    this.clear();
    this.transformContext();
    context.beginPath();
    for(var t = 0; t <= 3; t += 0.003) {
        context.lineTo(xeq(t), yeq(t));
    }
    context.restore();
    context.lineJoin = 'round';
    context.lineWidth = thickness;
    context.strokeStyle = color;
    context.stroke();
    context.restore();
};
```

- Amplitude.js performs the amplitude modification by position adjustment of knob on the gauge;
- Frequency.js has the same functionality as Amplitude.js, applied for frequency adjustments;
- Lissajou.js and Signal.js use functions defined in Graph.js and

implement the mathematical structure for the signal generator and oscilloscope. These functions accept three parameters: the amplitude, the frequency and the phase;

```
define(['graph','jquery'], function (Graph,$) {
    function Lissajou(displayId){
        this.myGraph = new Graph({
            canvasId: displayId,
            minX: -10,
            minY: -10,
            maxX: 10,
            maxY: 10,
            unitsPerTick: 1
        });
    }
    Lissajou.prototype.drawLissajou = function(amp, freqv, phase){
        function xliss(t) {
            return amp*Math.sin(2*Math.PI*freqv*t);
        }
        function yliss(t) {
            return amp*Math.sin(2*Math.PI*freqv*t+phase);
        }
        this.myGraph.drawParametricCurve(xliss,yliss,'#ffff66',4);
    };
    Lissajou.prototype.drawSpot = function(){
        this.myGraph.drawSpot('#ffff66');
    };
    Lissajou.prototype.clear = function(){
        this.myGraph.clear();
    };
    return Lissajou;
});
```

– Phase.js uses the microphone position to calculate the phase difference between the oscilloscope signals;

– Colorgen.js and Wave.js are used to achieve the animation of the sound into the layout of speakerphone – microphone.

Thus, the end user can start the generator and the oscilloscope (Fig. 3). The amplitude and frequency can be adjusted by using the sliders from the signal generator. The phase shift changes by varying the position of the microphone and appearance of Lissajous figure occurs. All virtual changes and adjustments are carried out to observe a real experiment in a similar way.

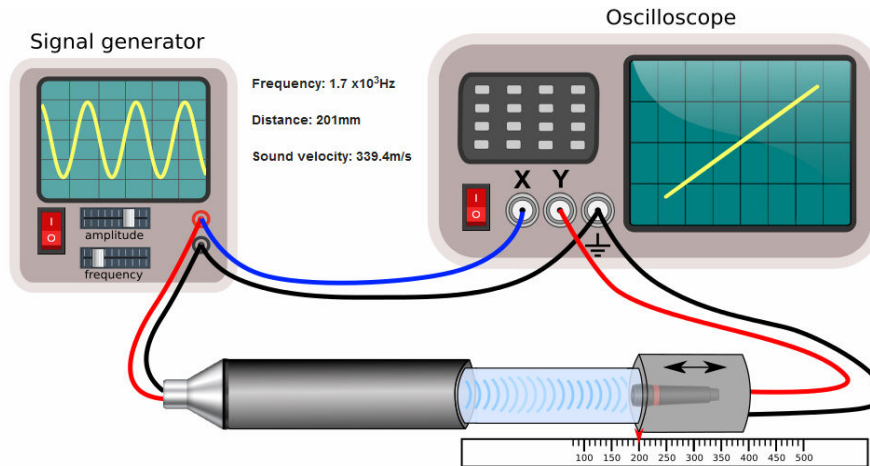


Fig. 3 – Experimental setup animation.

4. Conclusions

Physics simulations are interesting and powerful tools in education because support tasks like easy learning and study of physical phenomena. They do not impose much burden as the traditional activity in the physics laboratory and in this way, the time spent for study physical phenomena and laws can be reduced. In addition, working with them does not require a deeper understanding of the simulation program. Also, physics simulations provide the students with important steps in their educational progress.

In recent years, in order to support and facilitate the learning of physics phenomena we have developed some physics simulations (Radinschi *et al.*, 2008; Radinschi & Damoc, 2008; Radinschi & Aignatoaie, 2010). The newest is the simulation used for the study of two perpendicular harmonic oscillations of the same frequency and for the evaluation of the speed of sound. Using this physics simulation the students improved their skills of working in the physics laboratory and also have obtained better performance in the learning process. This is because they have only to follow the defined instructions for using the physics simulation and make a comparison with the picked up experimental data. Likewise, in this way they learn by observing the simulation of the physics phenomena and, also working in the physics laboratory. Moreover, the physics simulation is posted on the website of our faculty at the address <http://server.ce.tuiasi.ro/~radinschi/simulation/default.html> in the virtual physics laboratory replacing the face to face learning and there will not be time and distance limitation. We consider that in this way the self-study and Internet based discussions are powerful tools for improving the students' learning

enthusiasm. As for the future work, for providing the students with an adequate environment for working in the physics laboratory we want to address other computational programs and elaborate more physics simulations.

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STUDIUL ASISTAT DE CALCULATOR PENTRU SIMULAREA A DOUĂ
OSCILAȚII
PERPENDICULARE DE ACEEAȘI FRECVENȚĂ

(Rezumat)

Scopul acestei lucrări este studiul a două oscilații armonice perpendiculare de aceeași frecvență folosind tehnologiile de programare HTML5 și JavaScript. Cu ajutorul acestor tehnologii s-a dezvoltat o simulare a proceselor fizice ce au loc în lucrarea experimentală. O aplicație experimentală este determinarea vitezei sunetului în aer. Această aplicație reprezintă subiectul unei lucrări de laborator aferente cursului de Fizică din semestrul doi al primului an de studiu al Facultății de Construcții și Instalații a Universității Tehnice "Gheorghe Asachi" din Iași. Utilizând tehnologiile HTML5 și JavaScript studenții vor fi mai motivați să lucreze mai rapid și vor beneficia de o înțelegere optimă a fenomenului fizic privind mișcarea oscilatorie. În plus, pentru reprezentările grafice a fost utilizat programul Matlab.