Educational experimental setup based on laser beam scanners

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Abstract

We present a simple experimental setup based on two optical scanners to control a laser beam for a series of educational experiments. It was verified that this simple design, broadly used for spectacular laser-show presentations, can also significantly help the educational process for interested in physics undergraduate students mainly of art orientations, which might have a lower scientific or technological background. Comparison with an oscilloscope proved that the system accurately replicates the oscilloscope output (Lissajous figures), when two sinusoidal signals of various frequencies and phases are used as inputs. The Lissajous figures are demonstrated on the lab wall as a spectacular image that attracts the interest of the students to further study the underlying phenomena, without any need to educate them on complicated instruments such as oscilloscopes. The experiment awakens an additional motivation to study several issues related to laser radiation such as the scattering of the beam in the air, laser intensity and it is useful as an introductory experiment before presenting double-slit interference or direction of light experiments. Additionally, it can be used to measure the frequency of an unknown acoustic signal generated by a tuning fork, the phase difference between two signals and the wavelength and the velocity of sound.

1. Introduction

Advances in sensors' technology, computer hardware and Internet software have made the realization of educational physics experiments much easier in recent years. Simple experiments such as the measurement of the sound velocity in air are still important for the educational process in physical sciences and several educational setups have been recently proposed [1-5]. However, experiments that can excite the interest of the student and simultaneously act as a learning exercise for basic physical concepts are very difficult to design and implement. Complex optical phenomena and spectroscopy can also act as good educational experiments for students in physics departments [6], but simpler and more eye-captive experiments are needed in the case of students with art orientation, such as in art conservation departments.

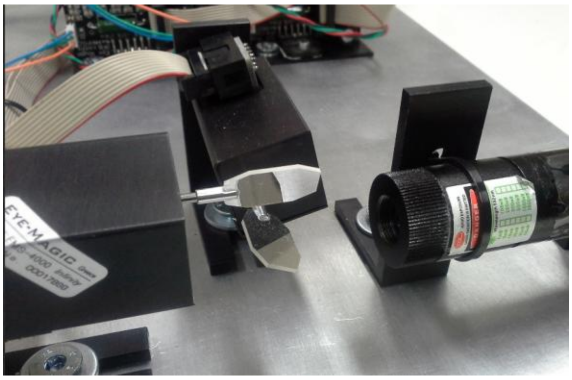
In this paper we present an experiment, which combines, in a visually intriguing way, the familiarization of the students with modern laser and laser scanning equipment, the understanding of the concepts of waves, and the implementation of several experiments and measurements, such as the measurement of the velocity of sound in air, without the need to educate them in complex devices such as an oscilloscope.

2. Experimental setup

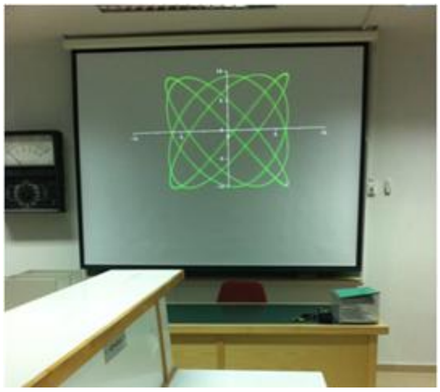
Two laser galvanometer scanners (Eye magic EMS-4000) with 6.8x12 mm dielectric mirrors and their servo drivers are used to separately control a green laser beam (40 mW) at X and Y axis.

Each scanner can take input from the amplified signal of a microphone or a frequency generator (to provide the sinusoidal voltage for the X or Y axis). A large screen at the Physics Lab is used for the simultaneous projection of a calibrated X-Y axis scheme to help measure distances as is shown in figure 1.

The setup used for the measurement of an unknown frequency, phase difference measurements and the velocity of sound is shown in figure 2. In figure 2(a), a tuning fork generates a sound wave that is converted to an electrical signal by a microphone and used as input to the Y-axis scanner. A sinusoidal frequency generator provides input to the Y-axis scanner. The observation on the wall screen of the Lissajous figures and the measurement of the ratio of the two frequencies (one is the known frequency of the generator and the second the unknown of the tuning fork) makes possible the determination of the unknown sound frequency.



(a)



(b)

Figure 1: (a) The experimental setup with the scanners, their controllers and the Laser pointer. (b) The Lissajous figures shown on a large screen at the Physics Lab, by simultaneous projection of the calibrated X-Y axis scheme to help measure distances.

In figure 2(b), the setup for the phase difference of two sinusoidal signals is presented. The phase difference can be measured by the Lissajous figures, using two microphones to convert sound waves to electrical signals that are applied at the X-Y scanner system. Additionally by measuring the phase difference between the sinusoidal input to the sound source and the microphone signal at different separation distances between them the sound velocity was measured.

(a) (b)

Figure 2: (a) Unknown frequency measurement setup. (b) Phase difference and velocity of sound measurements setup.

3. Experimental results

3.1 Scattering of light effects and laser beam show

In order to excite the interest of the students, it is effective to start the experiments with an easily implemented laser show. The Y-axis is set in a certain position and a sinusoidal signal is used for the X-axis. Smoke can be used in order to make more impressive the beam effects. This show can act as a trigger to discuss with the students the phenomena of the scattering of light by small particles.

Small particles, the size of which approaches that of a wavelength of light, scatter light, as do atoms, and molecules. If light is scattered by particles the size of the order of the wavelength of light or greater, like dust particles, Rayleigh scattering strong wavelength preference is not seen in the scattered light. Large-particle scattering (Mie scattering), unlike Rayleigh scattering, can be strongly directional.

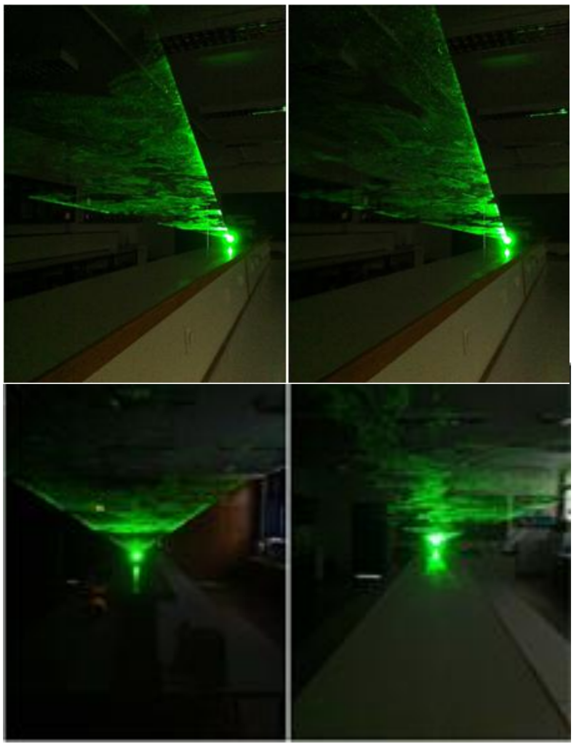
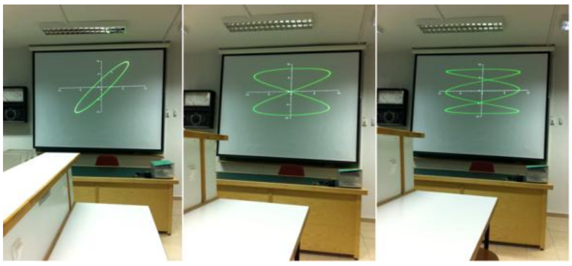


Figure 3: Demonstration of the scattering effect of the laser beam show. Smoke or dust particles can be used to amplify the phenomenon.

3.2 Unknown sound frequency measurements

The unknown frequency of a sound wave generated by a tuning fork can be easily measured if a microphone is used to convert the sound signal to electrical input into the X-axis scanner. A frequency generator is used in the Y-axis. The frequency of the signal generator was adjusted so that a steady Lissajous pattern is obtained. The ratio of the number of horizontal to vertical loops is the ratio of the unknown frequency to the known frequency f_{unk}/f_0. An accurate measurement of the 660 Hz tuning fork frequency was possible as is shown in figure 4.



(a) (b) (c)

Figure 4: Unknown sound wave frequency measurement of a 660 Hz tuning fork. In (a) the frequency generator f_0 is set at 660 Hz and the ratio of the unknown frequency f_{unk} to generator frequency $f_{unk}/f_0=1$, (b) $f_0=330$ Hz and $f_{unk}/f_0=2$, (c) $f_0=220$ Hz and $f_{unk}/f_0=3$.

3.3 Phase difference and velocity of sound measurements

When two signals of the same frequency are used as input to the scanners, Lissajous figures form on the screen an ellipse, the intercept and the maximum height of which could be used to determine the relative phase, according to the ratio of the amplitude of the two signals. So the phase difference between two sinusoidal signals, as those generated by two microphones, can be estimated by $\varphi=\sin^{-1}(B/A)$, where B and A are shown schematically in figure 5.

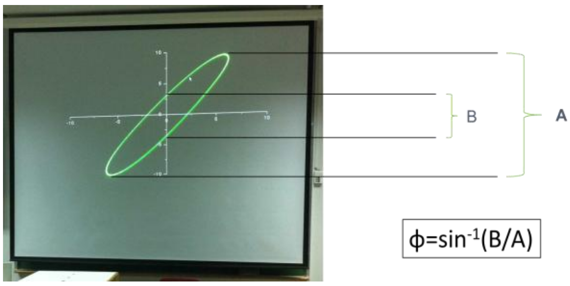


Figure 5: Phase difference Φ measurement between two sound waves of the same frequency

A frequency generator is used for the generation of a sound wave through a speaker in a frequency $f_0=600$ Hz. This is the input in one scanner, while a microphone is placed in a distance S to record the sound and convert it into the electrical input of the second scanner (figure 6). Initially the microphone has been positioned such that the signals from the speaker of the frequency generator and the microphone are in phase, resulting in a diagonal line. As the microphone is moved away from the speaker, its signal lags in phase with respect to that applied to the speaker, due to the propagation of the sound wave. The phase difference between the two signals can be easily retrieved from the elliptical pattern.

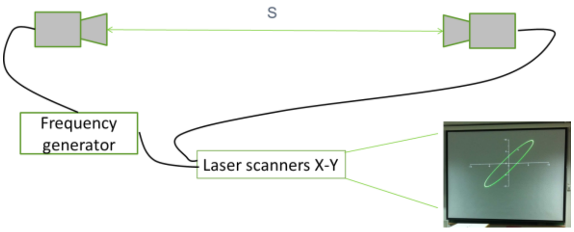


Figure 6: Sound velocity measurement setup, using the phase difference between the source sound wave (speaker connected to the frequency generator and fixed at a specific place) and the signal recorded by a microphone at different observation distances S from the speaker.

Varying the separation distance S between 2 cm to 120 cm will lead to the series of measurements shown in Table 1. The wavelength λ was calculated as $\lambda=S\cdot(360/\Phi)$ and the sound velocity by $v=\lambda\cdot f_0$.

Distance S (cm)	A (cm)	B (cm)	$\Phi=\sin^{-1}$ (A/B)	λ (cm)	v (m/s)
2	24	120	12	62	374
4	56	120	28	52	311
6	72	120	37	59	352
8	98	120	55	53	316
10	104	120	60	60	360
12	116	120	75	57	345
14	120	120	90	56	336

Table 1: Sound velocity experimental data. Room temperature was $T=23^oC$, $f_0=600$ Hz.

The series of measurements shown in table 1 can be easily conducted by students measuring the distances A and B on the distant wall. The table results in a sound velocity equal to **v = (342 ± 9) m/s**, in good agreement with the theoretically estimated velocity of 344 m/s at the room's temperature.

Variation of the signals occurred due to changes in the microphone pickup of reflections in the room, since the experimental setup was too sensitive that could change as we moved around near the apparatus. Elimination of those side effects was done by selecting a high frequency and by aiming the sound toward a distant wall or a region with no sound reflections.

4. Conclusions

The proposed laser scanner setup excited the interest of the students in experimental physics and helped them to understand different complex concepts in laser physics, oscillations, waves, the concept of phase in waves etc. and it can efficiently substitute the oscilloscope as a measuring instrument. In addition, the educational significance is greater for students with direction to art conservation, outside the narrow limits of the Physics experiments, in which this setup is used in principle with appropriate software for controlling the laser beam, scanning large surfaces, in order to clean mainly flat artwork.

5. Literatur

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