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An indispensable modified screen to assist automated optical fringe counting

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Abstract

In this article, we describe a simple experimental proposal for a modified screen to assist automated fringe counting in laser interferometry experiments. We choose a Michelson interferometer (MI) as our model experiment that has been reported in the literature (PHYWE Systeme GmbH & Co. KG 2017 Catalogue: Physics & Applied Sciences University Experiments (Michelson interferometer, item number: P2220500), https://www.phywe.com/en/top/downloads/catalogue-download/) and frequently practiced in the laboratory. The calculation of wavelength by exploiting MI requires a tedious manual method of counting fringes with the naked eye, which causes error in the measured wavelength. This error is elegantly avoided with the proposed screen, which has a small needle-sized hole at its center for the passage of light. It is also equipped with a digital fringe counter (using an ordinary calculator) combined with a photodiode (used as an optical sensor) installed at the rear side of the screen directly beneath the central hole. In principle, every time the central bright circular fringe falling on the screen replaces the dark one, the change is efficiently sensed by the photodiode, which sends a pulse to the calculator that will cause it to show an increment in its display. Our results show greater accuracy of measurement using the proposed fringe counter as opposed to the tedious traditional method. These results strongly recommend that a stand-alone digital screen with in-built light sensor and counting display is adopted and manufacturers (for example, PHYWE Systeme GmbH & Co. KG, PHYWE webpage (www.phywe.com)) should include it in their MI setups. To the best of our knowledge, this paper is the first to propose this kind of digital screen. Finally, in this modern age of electronics, the proposal will be a vital addition to all physics laboratory experiments that involve the concepts of fringes, optics, laser interferometry, interference and electronics.

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Keywords: Michelson interferometer (MI), optical screen, fringe counting, laser interferometry, modern physics laboratory

(Some figures may appear in colour only in the online journal)

1. Introduction

Laser interferometry is at the core of every modern physics teaching laboratory. The renowned Michelson interferometer (MI), belonging to laser interferometry, is frequently used in science laboratories at college and university level [1]. The main aims are focused on determining the laser wavelength, refractive index and microscopic displacements; assessing the optical quality of lenses; finding the coefficient of thermal expansion of copper; and measuring thickness, to name a few. A survey of the literature on physics teaching [1–8] reveals that interferometer setups have been used for quite a long time. For this study, we have chosen an MI (manufacturer: PHYWE Systeme GmbH & Co. KG, reference [1]) as our model laser interferometry experiment. The main motivation behind this experiment was to compute the wavelength of a light source with less error. We formed five groups of undergraduate students (in their third year of university) with three members in each group. All groups observed the interferometer fringes, counted them and then estimated the wavelength of the light source. They performed the experiments, systematically, by employing both the traditional method (TM) and proposed method (PM). The details of these methods will be presented in the next sections.

This article is organized in the following way. In section 2, a general description and phenomenology of the MI from the perspective of the TM is presented. In section 3, we present the experimental part containing an overview of the PM together with discussion of the obtained results. Finally, section 4 is devoted to the conclusions.

2. Michelson interferometer

A schematic view of our experimental MI setup is depicted in figure 1. We used a red He–Ne laser (632.8 nm, 1.0 mW, 220 V AC) as the light source. In principle, when the waves add in phase we should observe constructive interference and when they add out of phase there should be destructive interference. When this concept is applied to the MI setup, circular interference fringes will be created and displayed on the screen. The observed interference pattern will be of use in calculating the wavelength of the laser light source.

In figure 1 there are two mirrors (M_1 and M_2), a half-silvered mirror referred to as a beam splitter (BS), a lens (L), and an ordinary optical screen (S). At the back of M_1 a micrometer screw gauge (SG) is installed for particularly small displacements. For simplicity, we have explicitly avoided the methodological detail and we encourage the reader to consult the references [1, 5, 9, 10] for further details.

In order to compute the wavelength (λ) using TM, the thimble of the SG is twisted counter-clockwise, which ultimately moves the mirror M_1 a distance D given by

$$D = k'd. \tag{1}$$

Here, d is the distance read off the scale of the SG and k' is a constant equal to 0.1 (called lever reduction 1:10) [1]. The corresponding dark-to-dark central circles or number of fringes (n), restored to their original state, are thus counted from S by the naked eye. Finally, the

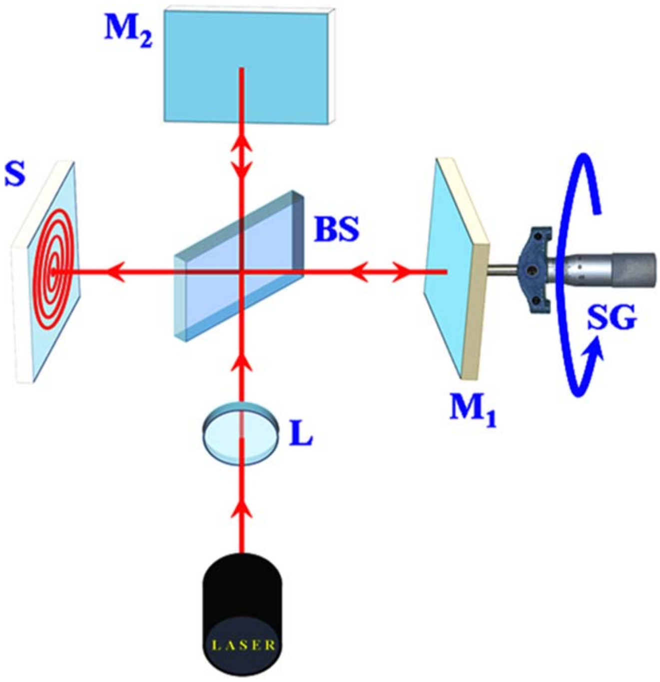

Figure 1. Schematic view of the Michelson interferometer (MI) experimental setup consisting of a He–Ne laser, diverging lens (L), mirrors (M_1 and M_2), beam splitter (BS), micrometer screw gauge (SG) and screen (S).

wavelength is calculated as

$$\lambda = 2D/n. \tag{2}$$

The above equation can also be used to measure the distance D of mirror M_1 if λ is known.

It is worth mentioning that in the MI experiment the counting is very much affected by errors related to one's expertise, such as start-stop (or reaction time) error, eyesight and temperament to keep one's eyes wide open during the fringe counting process (in a dark room). A slight blink or twinkle (i.e. human error) can cause huge error in counting and ultimately in calculated wavelength as M_1's manual displacement is finally recorded from the SG scale (see equation (2)). Hence, an automated screen is reasonably indispensable in this kind of experimental setup.

3. Experimental

3.1. Proposed screen

The notion of fringe counting is already present in the literature [11]. However, we attempted to utilize it in a simple and interesting manner to overcome the difficulties faced by laboratory students. In figures 2(a) and (b) we describe the schematic view of our proposed screen and its circuit. In fact, we exploited the internal circuit of a cheap pocket calculator (used as the counter) together with an ordinary photodiode (PD) as the light sensor, enclosed in a suitable casing at the rear side of the proposed screen (see figure 2(a)). In addition, a small hole was

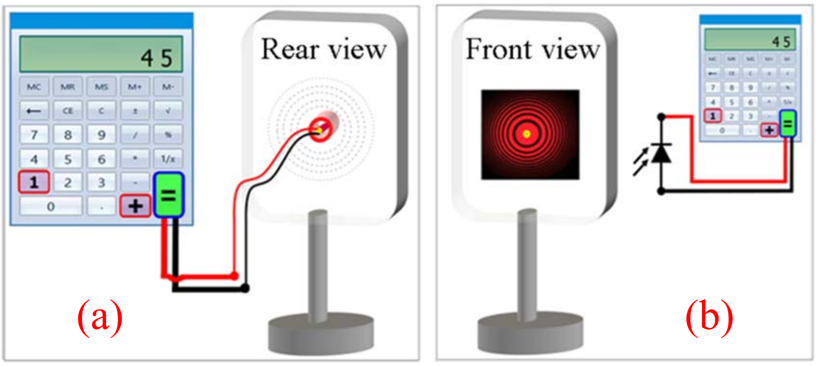

Figure 2. (a) Schematic view showing counting mode of the calculator together with a photodiode (PD) as a sensor connected at the back of the screen. Adjustment is simply carried out by pressing the '1' and '+' keys, and then continually pressing the '=' key. (b) Front view of the screen with the PD (shown by the yellow spot) at the center of the circular fringes. The inset shows the connections of the PD to the calculator '=' key forming a closed sensing circuit.

drilled through the screen's front side such that the PD receives only the desired incident laser light (thus eliminating the influence of external or surrounding light). In figure 2(b) the front view of the proposed screen together with the location of the PD (indicated by the central yellow spot) and its equivalent sensing circuit are depicted.

In principle, it is quite straightforward to adjust the calculator to counting mode only by pressing the '1' and '+' keys and then continually pressing its '=' key to obtain an increment in the displayed number (for example: 1, 2, 3, 4, …). At this point, it is important to clarify that not all calculators may work for this task. For example, as a simple test, if the chosen calculator does not show an increment and instead displays '1' each time its '=' key is pressed, then it should be discarded. In brief, whenever laser light in the form of circular fringes (especially the central fringe) falls on the PD, the circuit is activated and the calculator starts to count (see figure 2(b)). Subsequently, each time a fringe passes over the PD, the calculator adds an increment of 1 to its count.

Herein, we also provide the necessary construction details of how to modify a pocket calculator to be used as counter. In figure 3(a) we present an actual photograph of our working model to assist automated fringe counting in optics and laser interferometry experiments. In figures 3(b) and (c) we show photographs depicting the front view of the chosen pocket calculator with and without its plastic sheath, respectively. It is interesting to learn that the plastic sheath houses a double-sided printed circuit board (PCB). The front side of the PCB contains keypad sensors as shown in figure 3(c). Every keypad sensor is connected to two dark regions or tracks (with in-built drilled holes) that pass signals corresponding to the keys pressed. With very little effort, these tracks are easily identifiable. We identified the tracks of the '=' key, shown by the shaded regions, and then marked the locations of the drilled holes to be used for wire connections as point 1 (black dot) and point 2 (red dot) as illustrated in figure 3(c).

Similarly to above, in figures 3(d) and (e) we show photographs depicting the rear view of the chosen calculator (with and without its sheath, respectively) with batteries, integrated circuit, the necessary circuitry and connections to the LCD. We recognized the above two tracks corresponding to holes 1 and 2 of the '=' key (see figure 3(e)) and soldered wires onto them. These wires were then led outside the calculator's sheath and connected to the two

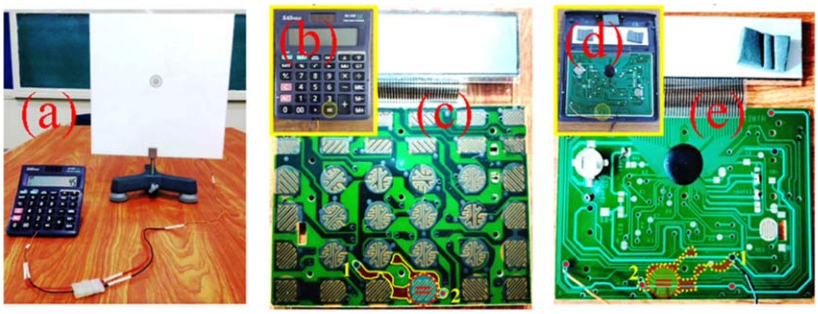

Figure 3. (a) Actual photograph of a working model showing the counter (calculator) and sensor (PD) connected to the centre of the screen. Here, the marked circle is a visual guide to adjust the central fringe exactly on the sensor. Front view of the calculator: (b) with its plastic sheath, (c) without its plastic sheath showing the PCB that contains the keypad sensors. The shaded regions show the connections of the '=' key marked as solder points 1 (black dot) and 2 (red dot). Rear view of calculator: (d) with its plastic sheath, (e) without its plastic sheath showing the connection tracks on the PCB corresponding to the '=' key.

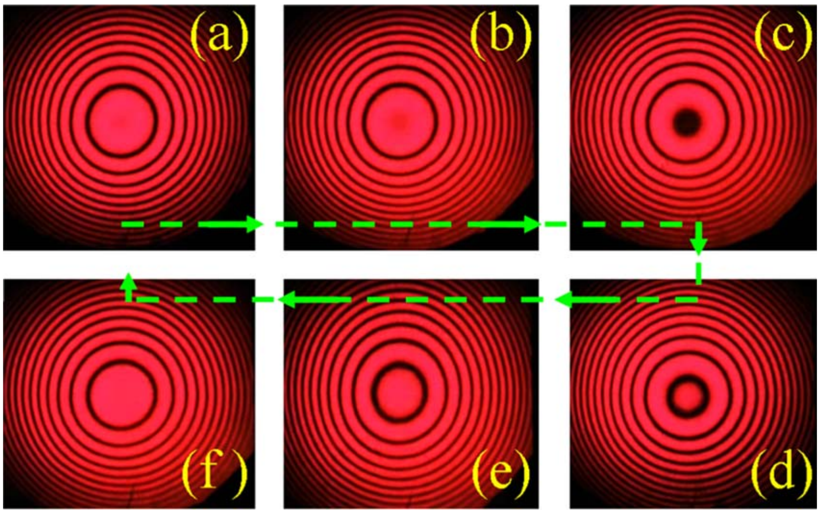

Figure 4. Experimentally observed screenshots for counting one fringe from the proposed screen (S) in a clockwise direction: (a)–(c) depict counting of one fringe as the central bright part is replaced by a dark one. (d)–(f) depict the slow emergence of a bright part and (f) resembles the original situation of figure (a). Figure (c) is the key position for the sensor (PD).

terminals of the PD installed at the rear side of the screen as shown in figure 3(a) (see also figure 2).

Let us shed some light on the experimental fringe counting process, by incorporating the above discussion, and showing actual images of the fringes (to elaborate on our proposed idea). In figure 4 (assuming a clockwise direction), we describe the counting process for a single fringe by showing one complete cycle of our experimental results in the form of snapshots of the screen.

Assume that figure 4(a) represents the instant when the experiment is ready to start (any position). At this position, there is a complete central bright circular part that fully covers the face of the installed PD. As the position of the SG thimble is twisted, the central bright circular part begins to diminish. Figure 4(b) shows the instant when the central dark part is very close to emerging. Next, the thimble of the SG is rotated further until a complete dark circular part (see figure 4(c)) is observed. In fact, this figure 4(c) is the true starting point of the counting cycle. This dark–bright circle change is sensed by the PD, which sends a pulse to the calculator that will cause an increment in its reading.

Figures 4(d)–(f) depict the slow emergence of the central bright circular part. In fact, figure 4(f) resembles the original situation (figure 4(a)). Turning the thimble position further, one arrives at figure 4(c) where the dark circular part is again sensed by the PD. This completes one cycle (dark–bright–dark) for counting a fringe. Clearly, the already mentioned (human) error owing to manual fringe counting is avoided very elegantly with the proposed setup.

3.2. Results and discussion

In this section we describe our main experimental results obtained by five different groups of students by resorting to the traditional method (TM) and proposed method (PM) with the MI setup. A comparison of the experimental wavelengths obtained for different numbers of fringe counts (n) is shown in figure 5. The dashed line shown is a visual guide that represents the accepted value of the laser's wavelength (632.8 nm). In figure 5(a) we describe the results obtained by using the TM of manual fringe counting with the naked eye. Clearly, there is a huge difference between the measured and accepted value (shown by the dashed line) of laser light used. In figure 5(b) we describe the results obtained using the PM of automated fringe counting. The measured wavelengths thus obtained are much closer to the accepted value.

We have also exclusively performed error analysis on the results acquired by the five different students groups, using both methods (TM and PM). The percentage error is defined by the following relation:

$$\text{Percentage error} = \frac{|\lambda_{\text{measured}} - \lambda_{\text{accepted}}|}{\lambda_{\text{accepted}}} \times 100, \tag{3}$$

where $\lambda_{\text{measured}}$ is the experimentally measured value and $\lambda_{\text{accepted}}$ is the accepted (or true) value.

In brief, the percentage error values calculated using the results of the TM are 6.74%, 2.54%, 3.14%, 1.90%, and 1.38% for Group-1 to Group-5, respectively. However, when calculated using the PM the values become 1.96%, 0.66%, 0.70%, 0.78%, and 0.84% for Group-1 to Group-5, respectively. Moreover, the accuracy of the micrometer can be further seen from table 1, in which a comparison between the TM and PM is presented. The tabulated assessment values are acquired by Group-2 by repeating the experiment 30 times ($N = 30$).

Hence, it can be concluded (see figure 5 and table 1) that the obtained results show greater accuracy in the measurement of wavelength using the proposed digital fringe counter (PM), as opposed to the tedious alternative of counting with the naked eye (TM).

Finally, we shed some light on the limitations of the proposed screen. It is worth mentioning that the PM works on the assumption that the movement of the mirror M_1 is always in the same direction (i.e. the SG thimble is rotated counter-clockwise). However, if the mirror reverses direction accidentally, for example at the time of starting or stopping the M_1 movement, the device is still counting (adding fringes) but should instead be counting negatively. This could introduce a very small error that can be neglected if repeated

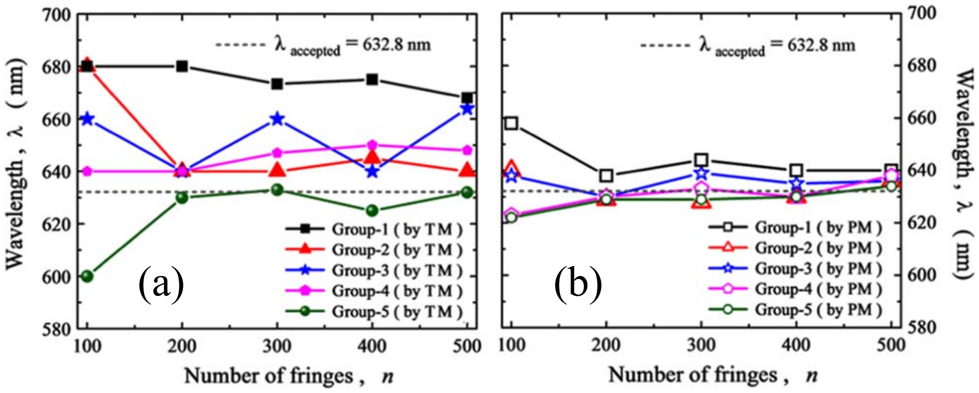

Figure 5. Comparison of experimental results obtained by five different students groups: (a) by using the traditional method (TM); (b) by using the proposed method (PM). The dashed line is a visual guide that represents the accepted value of the laser's wavelength.

Table 1. Summary of error analysis results for repeated experiments ($N = 30$). Here, number of fringe counts (n) = 100, d = screw gauge reading and $\lambda = 2\,k'd/n$ with $k' = 0.1$.

	Traditional method (TM)		Proposed method (PM)	
Assessment value	d (mm)	λ (nm)	d (mm)	λ (nm)
Mean	0.340	680.7	0.319	637.3
Standard deviation	0.018	35	0.014	27
Standard error	0.0032	6.4	0.0025	5.0

measurements are taken. However, very delicate and skilful movement of the SG thimble in a continuous direction will diminish this kind of error considerably.

The counting speed is mainly limited by the switching time of the PD. In fact, it can simply manage events that are separated by 100–200 ms, fixing an upper limit of 600 events/min. As in the MI experiment, the SG thimble is twisted very delicately by hand and consequently the counting speed is not an issue. In any case, the manual motion is always much greater than the switching time of the PD. The full range of motion of the mirror (M_1) in our experimental setup (see figure 1) is 0.55–0.6 mm (i.e. 5.5–6.0 mm on the main scale of the SG). Therefore, the counter can easily reach 1000 fringes. However, if the central point of the circles moves outside the marked spot on S (see figure 3(a)) a modest readjustment has to be performed (via M_2).

The above results suggest that not only are improvements to the TM very much needed in this modern age of computation and electronics, but also the PM of automated fringe counting is quite straightforward, interesting and quick from students' point of view. This will also encourage students to look at additional prospects of this and other optics experiments where fringe counting is a tedious exertion. We believe that, to the best of our knowledge, the proposed idea is innovative and will be very beneficial to students. We are optimistic that our proposed idea concerning a modified screen is an important advancement for laser interferometry and optics experiments for which the routine involves tedious (manual) fringe counting with the naked eye.

4. Conclusions

We have proposed a timely idea by providing modification to an already existing experiment in modern physics or optics laboratories on the phenomenon of interference (Michelson interferometer), often executed in undergraduate physics laboratories, by presenting an elegant method of automated fringe counting. We have adapted the ordinary screen to a digital one to indicate how this simple experiment can be extended to a novel one, using a widely available ordinary pocket calculator (counter) and a photodiode (sensor). In fact, the apparatus is simply a photodiode mounted on a screen, and wired to the '=' button of the pocket calculator. The results of the proposed method (automated digital fringe counter) have been compared with those of the traditional method (manual counting with the naked eye) and show greater measurement accuracy, and are found to be very acceptable. Owing to its ease and simplicity, the proposed method may well be exploited as a laboratory demonstration for students seeking exposure in the fields of laser interferometry, optics, waves and electronics. We have presented the details of measurements and calculations.

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