Experimental Realization of an Extremely Low-cost Quadrature Optical Interferometer

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Abstract: We report on the construction and characterization of a quadrature-detected optical interferometer that can be assembled on a budget of less than US$500, and in which quadrature detection is achieved by means of polarization control.

Optical interferometers form workhorse components of a wide array of scientific devices, with applications ranging from testing fundamental physics principles [1] to measuring velocities and positions with high precision [2,3] to characterizing material properties [4,5] to controlling and manipulating both classical and quantum light sources [6]. In light of this, there are significant benefits to bringing students into direct contact with interferometric devices at a hands-on level in undergraduate-level physics classes, and several companies have made interferometer demonstrations and advanced laboratory kits available at modest to intermediate prices.

Although commercially available interferometers enjoy the benefit of tech support teams and out-of-the-box functionality, there is a certain utility in pushing the limits of how cheaply interferometer components can be constructed and assembled while still preserving the basic functionality of the technique. Efforts along these lines both expand the boundaries of the maker movement and maximize access to scientific ideas. Here we report on the construction and characterization of an optical interferometer that can be assembled on a budget of less than $500, which is constructed almost entirely on top of a single 12”x6” plate of 1/2”-thick aluminum, and which exhibits automated data acquisition and quadrature detection sensitivity [7]. We use the interferometer to measure the thermal expansion coefficient of aluminum, and while measurements of this coefficient reveal quantitative inaccuracies, qualitative features are robust. We found the system to serve as an excellent pedagogical vehicle for teaching students about quadrature detection, wave plates, Jones matrices, circuitry, and experimental control protocols.

Figure 1(a) shows a photograph of the device. The laser source consists of a $25 green laser pointer purchased online from the company Dinofire. Fixed optics mounts (golden and white elements in the figure) are constructed out of 3D-printed parts. Quadrature detection is achieved by means of polarization control, with polaroid filters (i.e., linear polarizers) attached to the optics mounts at strategic locations, and with quarter-waveplate functionality achieved by inserting the filter from a pair of 3D movies glasses backwards into the interferometer’s lower arm just before entering the second of two beamsplitters. Photodetectors are constructed out of rudimentary photodiode-plus-resistor combinations, and the analog-to-digital converter (ADC) from an Adafruit Trinket M0 microcontroller is used to convert photodetector output signals into signals that can be read and stored in a computer.

Figures 1(b) and 1(c) show an example data set highlighting the interferometer’s ability to measure the thermal contraction effects of the aluminum sheet on which the interferometer is mounted in response to changing ambient

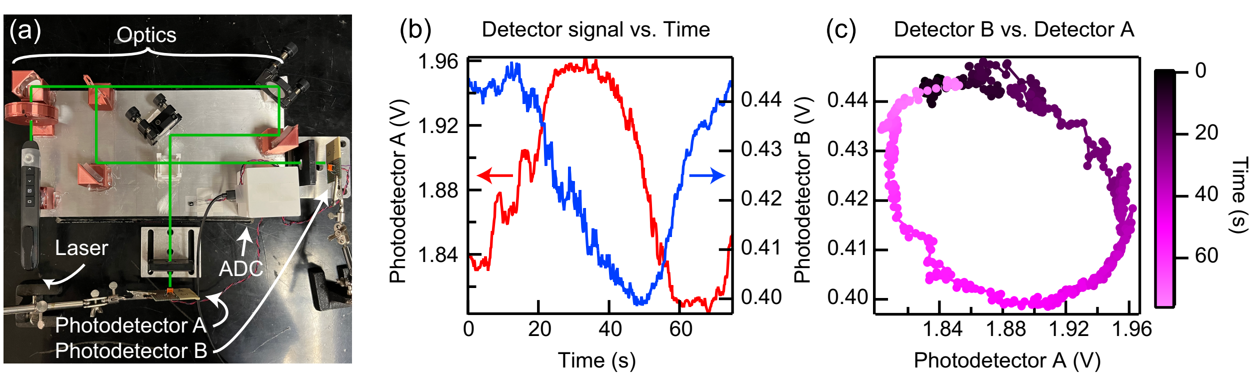

Figure 1: Interferometer design elements and example data set. (a) Photograph of the setup and cartoon illustration of optical paths. (b) Example data set showing the raw input signals collected by Photodetectors A (red trace) and B (blue trace) as a function of time. (c) Lissajous figure plotting the outputs of Photodetectors A and B against each other. Adapted from T. M. Melody, et al., Am. J. Phys., in press (2022) [7].

air temperature. Figure 1(b) shows a set of raw signals that were measured using two different photodetectors [labeled "Photodetector A" and "Photodetector B"; see Fig. 1(a)], plotted against time over the course of a 75-second period during which the ambient temperature of the room in which the interferometer was house was steadily decreased. Photodetector B can be seen to clearly approach a maximum fringe brightness during times when the brightness detected at Photodetector A is rapidly changing and vice versa, which is an indication that the two detectors have been appropriately oriented in quadrature.

Figure 1(c) shows a plot of the Photodetector B signal plotted directly against that of Photodetector A (a form of Lissajous figure), making it particularly easy to analyze whether quadrature detection has been achieved. In the case of perfectly aligned and oriented signals, this Lissajous figure would be expected to trace out a circular pattern on this Detector A vs. Detector B plot. As can be seen in Fig. 1(c), the line traced out by the measured signal features a somewhat elliptical structure, revealing deviations—possibly due to the imperfect quality of the low-cost optical components utilized—from the ideal theoretical case. Elongation effects are mild, however, leading to an ability to approximate the two signals as being in quadrature without introducing undue systematic errors.

As the ambient room temperature was lowered, we used a Texas instruments LM35 temperature sensor affixed to the aluminum plate to independently measure the aluminum plate's temperature, and we used the simultaneous measurements to come up with an estimate of the aluminum plate's thermal expansion coefficient near room temperature. We found that qualitative features are robust (the interferometer contracted when the room temperature lowered, and expanded when the room temperature rose), but quantitative estimates of the thermal expansion coefficient did reveal a few discrepancies. We measured a thermal expansion coefficient of $(79.4 \pm 1.4) \times 10^{-6}$ /°C while the value of this constant as obtained from the literature is more commonly quoted closer to 23.6×10^{-6} /°C [8]. These results set limits on the degree to which the constructed device can be used in practical settings, but at the same time they also underscore the potential of the device to be used in pedagogy. Applications may include use as a classroom demonstration model, and deployment of many devices or device kits in tandem to groups of students taking laboratory optics classes.

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