Broadband vis-NIR Fourier Transform spectrometer

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Abstract

Michelson interferometer which is invented by A.A. Michelson around 1881 is a cruciform interferometer that can measure the wavelength from atomic size to gravitational-wave size ($\approx 10^{-10} - 10^{7}$m) by interference with high accuracy. It is widely-used in modern physics research such as Gravitational Wave detection and Optical coherence tomography. In this study, a home-made automated Michelson interferometer is built up and used to collect the optical spectrum of the broadband light.

Introduction

Michelson interferometer is a set up using beam splitter to split the light into two arms. One of them will be transmitted and the other one will be reflected by the beam splitter, then both of them will be reflected by two mirrors which one of them is moveable. Note that two splitted beams have same oscillation frequency ω and wavenumber k.

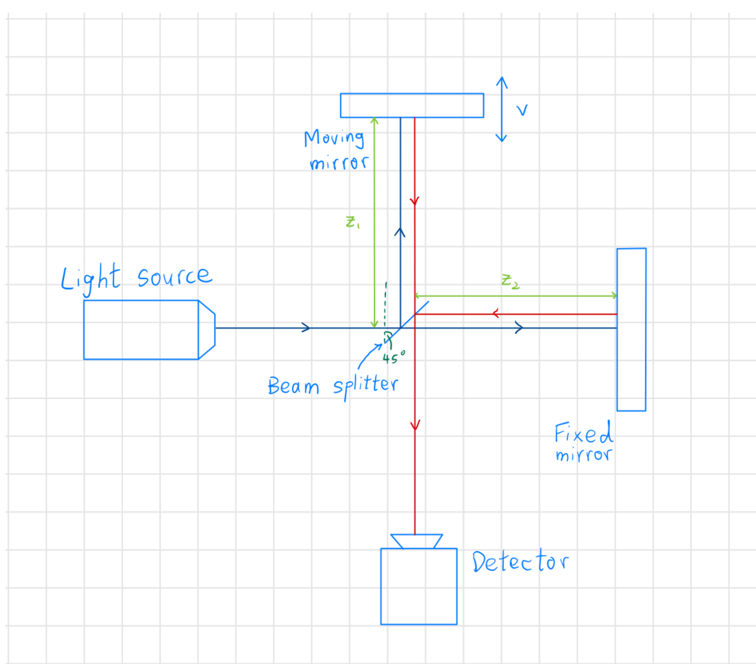


Figure: Schematic sketch of the Interferometer

Two splitted beams will superpose when they pass through the beam splitter again. The superposed beam have the electric field and intensity:

$$E(z) = E_0 \sum_{i=1}^{\infty} \cos(\omega_i t - k_i z_1) + \cos(\omega_i t - k_i z_2)$$

$$\mathscr{E}(\Delta z) = c\epsilon_0^2 E_0^2 + \sum_{i=1}^{\infty} \hat{\mathscr{E}}_i(k_i) cos(k_i \Delta z)$$

where $\Delta z = z_2 - z_1$ is the path difference between two arms. Interference occurs when:

- **The moving mirror moves with constant speed v**
- **The path difference smaller than the coherence length**

As the moving mirror moves in constant speed v, the change of path difference is fully determined by the displacement of the moving mirror, mathematically: $\Delta z = v\Delta t$. Which leads to a shift of the interference fringes.

The plot of the $\mathscr{E}(\Delta z)$ is called the **Interferogram**.

Simulation

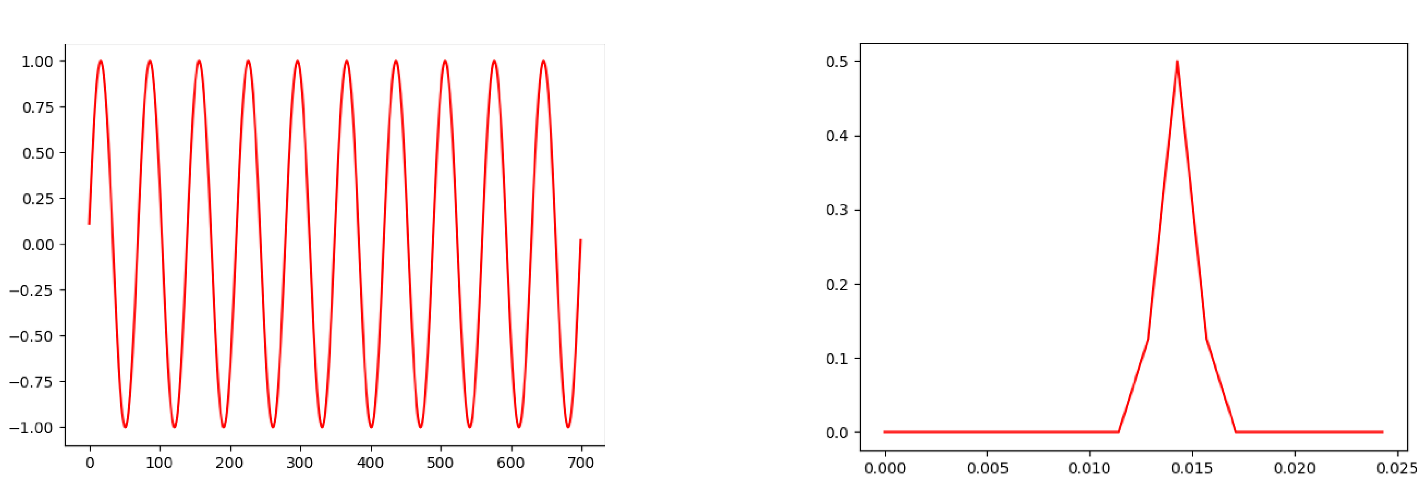


Figure: Single wavelength simulation

The single wavelength simulation showed the result for monochromatic light. The interferogram is a regular sinusoidal function and the optical spectrum is a Dirac-delta-like function.

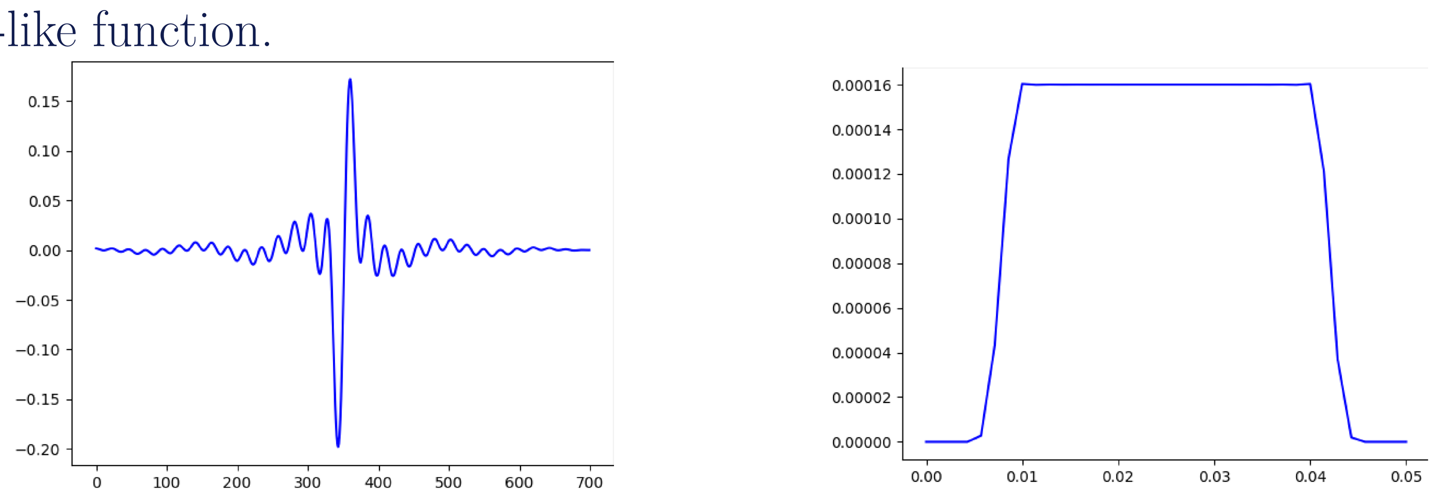
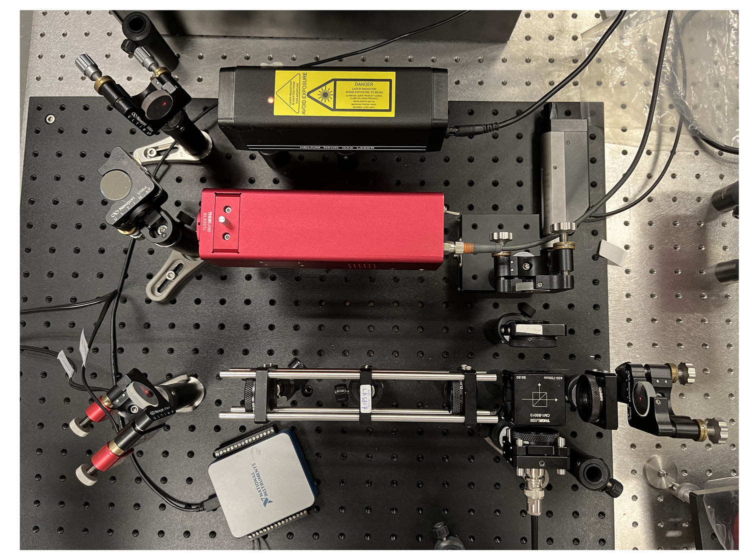


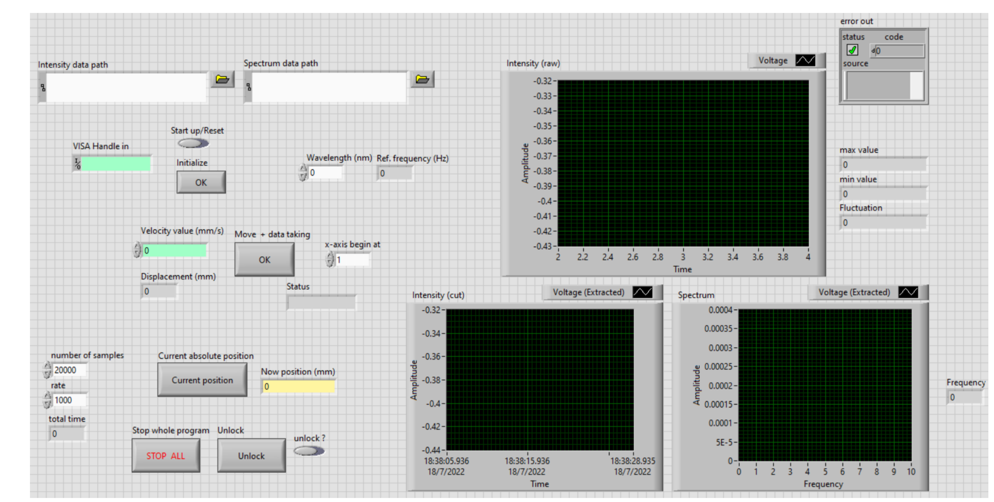
Figure: Broadband light simulation

The Broadband light simulation showed the result for Broadband light. The interferogram is a sum of sinusoidal functions and the optical spectrum is a Heaviside-like function.

Experimental setup



(a) The interferometer

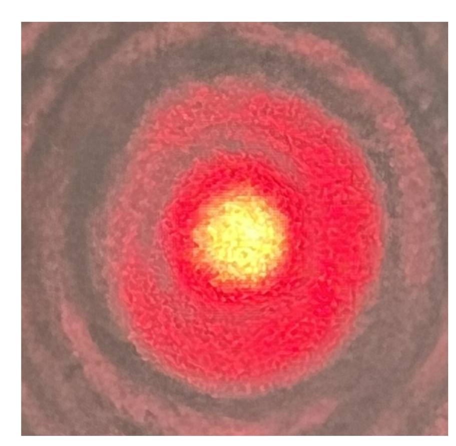


(b) LabVIEW program

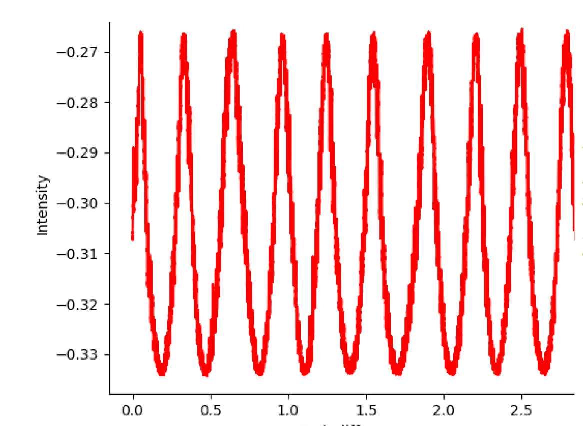
The main components include a broadband light source, a beam splitter, a fixed mirror, a scanning mirror and a detector. The scanning mirror is mounted on a motorized linear stage, is controlled to move by a controller.

Besides, LabVIEW is used for data acquisition and computation of optical spectrum correspond to the Interferogram.

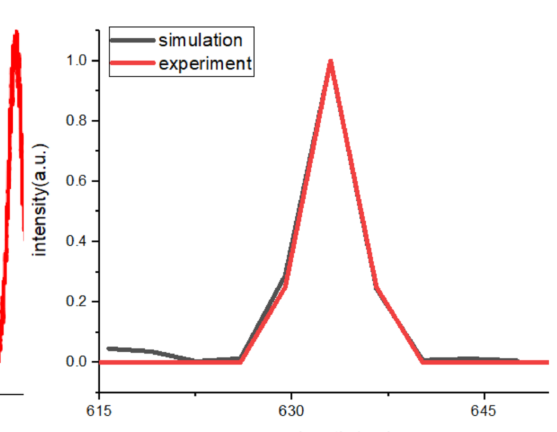
Monochromatic laser



(a) Interference pattern



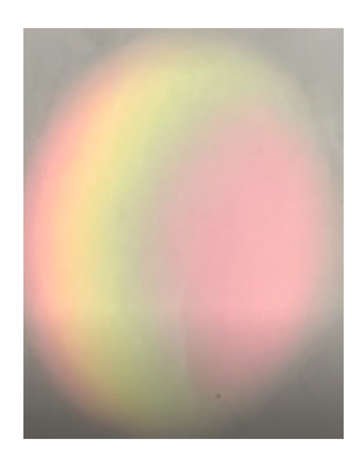
(b) Interferogram



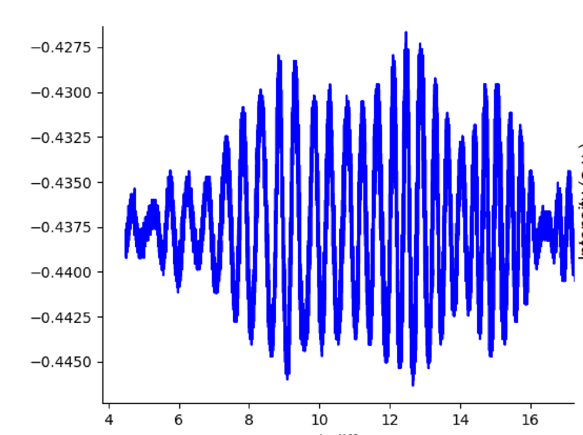
(c) Optical spectrum

The interference pattern, interferogram and the optical spectrum are shown above, it can be seen that the acquired data satisfy the simulation data. This gives us a successful test for the alignment of our home-build interferometer.

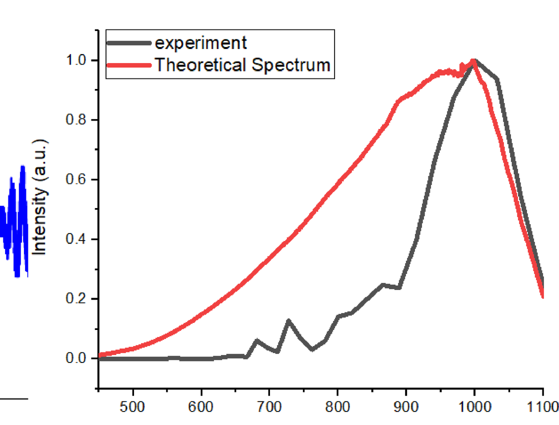
Broadband & Near-Infrared light



(a) Interference pattern



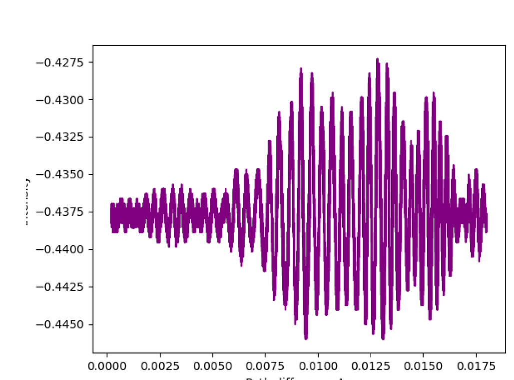
(b) Interferogram



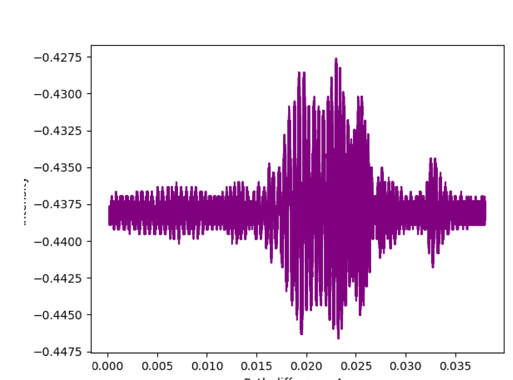
(c) Optical spectrum

The interference pattern, interferogram and the optical spectrum are shown above. Note that the power distribution of light source may not be even in the wavelengths, the comparison is between the power spectrum of the light source and the acquired data. Besides, it can be seen that there is a discrepancy between the experimental data and the spectrum of the light source, this is because the clotting on the mirrors and lens decrease the intensity of the beam each time when the beam is reflected or transmitted.

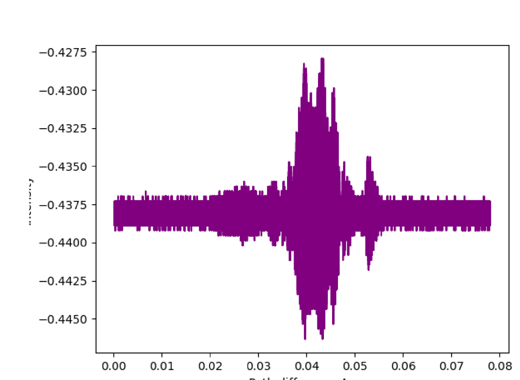
Resolution test



(a) $\Delta z = 0.018$



(b) $\Delta z = 0.038$



(c) $\Delta z = 0.078$

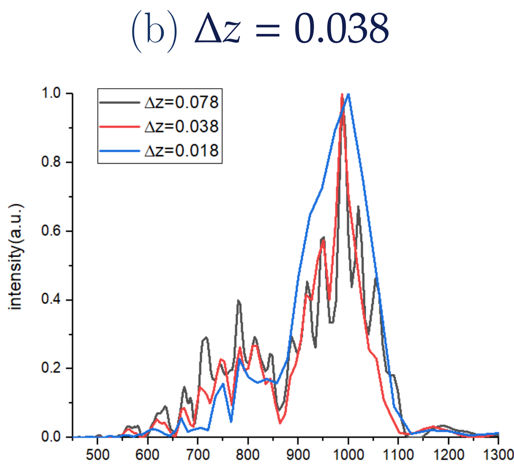


Figure: Optical spectrum for different scanning range

To increase the resolution of the Interferogram, a longer scanning range is needed. There are more raw data, after doing fourier transform, the $\Delta\lambda$ is smaller and the resolution is higher. This part shows the optical spectrum for different scanning distance.