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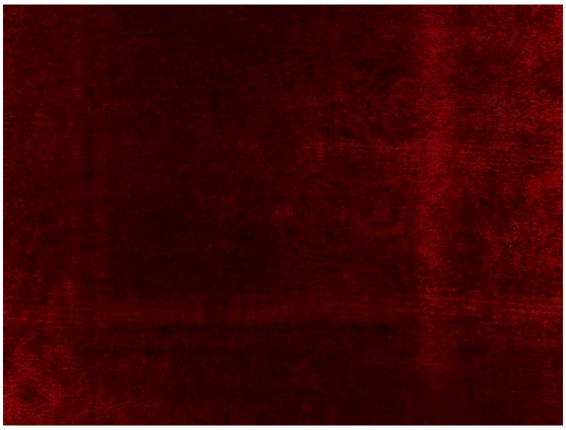
Interferometer

5. Summary of tasks of the experimental work

5.2 Zero optical path difference – ZPD (90 min)

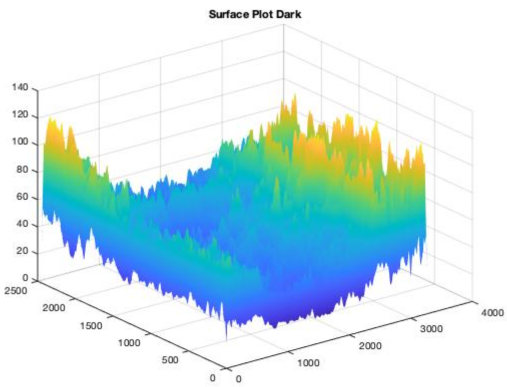
To be done for the report: Find the zero OPD position and plot the intensity profile as well as a surface plot for the low intensity state and the high intensity state. (**4 surface plots**). Take care that you use **equal exposure** conditions (no auto mode!!!) for both states to show the contrast correctly.

Picture 1–
Surface plot low intensity: (dark)

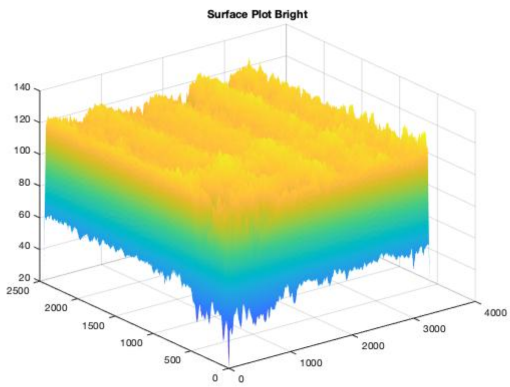


Picture 2–
Surface plot high intensity: (bright)

Graph 1–
Surface plot low intensity:



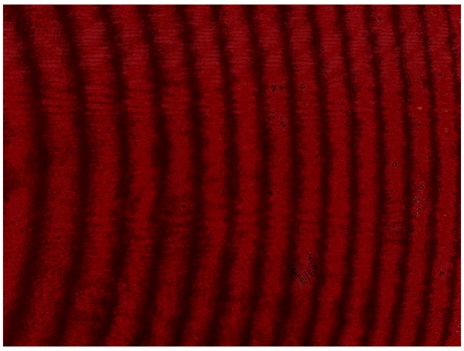
Graph 2–
Surface plot high intensity:

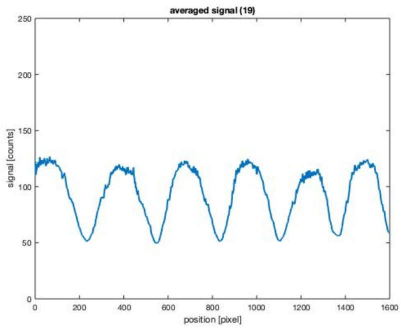


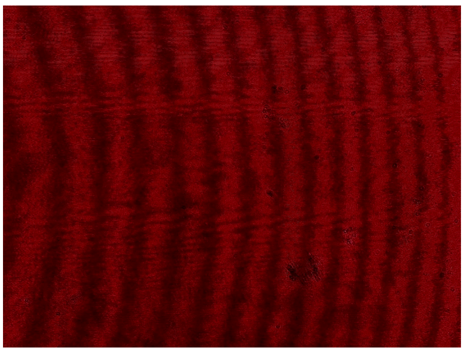
Comment why it is so difficult to align for the ZPD:
There are many parameters to consider. First the source is unique in itself and might have multiple frequencies (beating) (our laser has 2), and in addition we have spherical waves and not planar which makes the fringes appear tilted when misaligned. Second, the splitting cube must be perfectly aligned with both mirrors, well adjusted, so as to reflect both virtual sources to the same spot. Third, the mirrors themselves must be tilted correctly as to ensure correct orientation and reflection spot. With some less convenient sources it might be hard to adjust the distance (when the difference is not visible to the naked eye) and we might think we missed the contrast spots because we're moving too far etc. every one of those things can make one doubt when unaware of the imperfections that may play a role – sometimes even the bending of our platform of experiments can cause trouble, that's why these very expensive "auto leveling" tables are developed and used in optics labs.

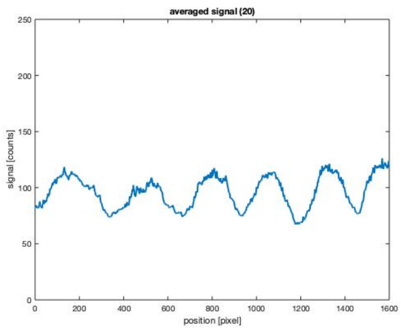
5.3 Measurement of laser fringe contrast (45 min)

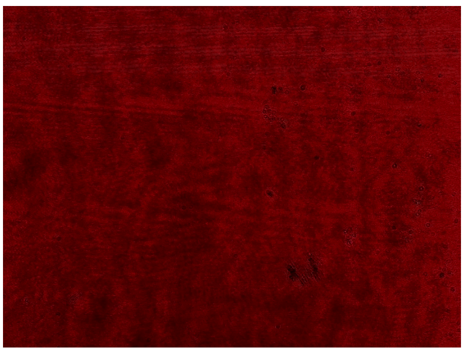
Show **three pictures** with different contrast and plot their line curve. (**3 line plots**)

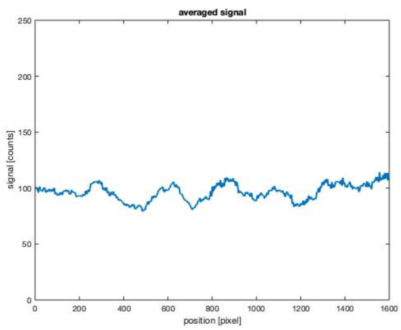












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Measure the contrast as a function of position of the translation stage (over more than 1 full cycles of contrast variation, minimum 30 points, use the table). **Step size 0.1 mm!**

Absolute position on the micrometer screw in mm	Relative position on the micrometer screw in mm	Contrast $C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$
3.8000	0.0000	0.5015
3.9000	0.1000	0.1822
4.0000	0.2000	0.1623
4.1000	0.3000	0.1875
4.2000	0.4000	0.1748
4.3000	0.5000	0.2073
4.4000	0.6000	0.2156
4.5000	0.7000	0.2489
4.6000	0.8000	0.2846
4.7000	0.9000	0.4031
4.8000	1.0000	0.4379
4.9000	1.1000	0.3224
5.0000	1.2000	0.3049
5.1000	1.3000	0.2512
5.2000	1.4000	0.2263
5.3000	1.5000	0.2507
5.4000	1.6000	0.2273
5.5000	1.7000	0.1891
5.6000	1.8000	0.2052
5.7000	1.9000	0.1814
5.8000	2.0000	0.1717
5.9000	2.1000	0.1921
6.0000	2.2000	0.2623
6.1000	2.3000	0.1911
6.2000	2.4000	0.2177
6.3000	2.5000	0.2462
6.4000	2.6000	0.2553
6.5000	2.7000	0.2473
6.6000	2.8000	0.3572
6.7000	2.9000	0.4424
6.8000	3.0000	0.3580
6.9000	3.1000	0.2193
7.0000	3.2000	0.1951
7.1000	3.3000	0.2393
7.2000	3.4000	0.1929
7.3000	3.5000	0.2236
7.4000	3.6000	0.2232
7.5000	3.7000	0.1849
7.6000	3.8000	0.2315

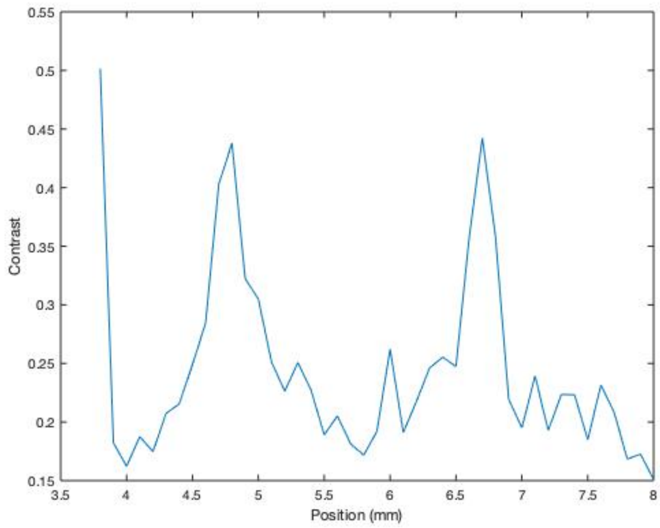
7.7000	3.9000	0.2084
7.8000	4.0000	0.1684
7.9000	4.1000	0.1726
8.0000	4.2000	0.1508

```
myDir = uigetdir;
myFiles = dir(fullfile(myDir, '*.jpg'));
contrast = zeros(length(myFiles), 1)
for k = 1:length(myFiles)
baseFileName = myFiles(k).name;
fullFileName = fullfile(myDir, baseFileName);
I_1 = imread(fullFileName);
Red_1 = I_1(:,:,1);
Red_1 = double(Red_1);
ROI_Red_1  = Red_1((600-100):(600+100),1:1599);
N_Avg_Red_1 = mean (ROI_Red_1);

mi = min(N_Avg_Red_1);
ma = max(N_Avg_Red_1);
contrast(k) = (ma-mi)/(ma+mi);
disp(contrast(k));

end
position = 3.8:0.1:8;
plot(position, contrast)
```

Plot the values. (**one graph**)



Contrast against mirror position. You should plot the position in mm.

Calculate the spectral widths of the source using the period of the variation. (Eq. 12, where Δz is the period found in your measurement!). Estimate the error of the measurement.

Source	Center wavelength	Spectral width	Coherence length
Halogen lamp (visible)	550 nm	300 nm (400 – 700 nm)	1 µm
LED	635 nm	20 nm	20 µm
Monomode laser	635 nm	0.2 nm	2 mm

The laser's datasheet

Our peak values are located at more or less z1=4.8mm and z2=6.7mm so **Δz=1.9mm**.

$$\Delta\lambda = \frac{\lambda^2}{\Delta z} = \frac{(635nm)^2}{1.9mm} = 0.21nm$$

Error estimation. One needs to calculate (analytically) the error $\delta\Delta z$ with the equation $\Delta z = \frac{\lambda^2}{\Delta\lambda}$

Now, we have $\delta\lambda$ = 0.25 nm (deduced from Figure 1 of the TP description and detailed in the slides)

This gives us $\Delta z = (635nm)^2/0.25nm$ = 1.6 mm

5.1

This is not the spectral width! It is the uncertainty of wavelength from the datasheet.

We need to find how well you can detect the peak distance in your graph!

So that $\delta\Delta z$ = 1.9mm – 1.6mm = 0.3 mm

So that $\delta\Delta\lambda = (635nm)^2/0.3mm$ = 1.34 nm

Next the error of the line distance can be found and the **result** is:

5.2

Δλ= □□□□□ (Δλ) ± □□□□□ (δΔλ) = 0.21 nm ± 1.34 nm

Comments: We see that our measurements are precise enough, allowing us to find back the value given in the datasheet with a low error.

5.4 WEB - Example

Find an example of an application where interferometry is the key technique. Print a picture; give a **short explanation** and parameters that are measured. Cite correctly.

"The Michelson stellar interferometer is used for measuring the diameter of stars. In 1920, Michelson and Francis G. Pease used it to measure the diameter of Betelgeuse, the first time the diameter of a star other than the sun was measured."

- https://en.wikipedia.org/wiki/Michelson_interferometer

"Michelson interferometry is the leading method for the direct detection of gravitational waves. This involves detecting tiny strains in space itself, affecting two long arms of the interferometer unequally, due to a strong passing gravitational wave. In 2015 the first detection of gravitational waves was accomplished using the LIGO instrument, a Michelson interferometer with 4 km arms"

- https://en.wikipedia.org/wiki/Gravitational-wave_observatory#Interferometers

In the latter, the strongest gravitational waves change the distance between the end of both arms by about 10^(-18) meters which is enough to change the interference pattern and allows us to measure the difference. This is of course an extreme case; the light passes through vacuum tubes and all sensors are state of the art components very sensitive to even the slightest variations. LIGO stands for Laser Interferometer Gravitational wave Observatory and is located in the USA. This allowed the first experimental validation of Einstein's general theory of relativity which predicted their existence. They now want to build even more advanced versions that would be about 10x more sensitive.

Personal feedback:

Was the amount of work adequate? Yes

What is difficult to understand? No

What did you like about it? Impressed by the web search, even though I already knew about it being used for gravitational wave detection.

How can we do better? Glad I didn't have to adjust this one…

Index of comments

5.1 0.25 nm is the emission linewidth but the error in the emission wavelength is 5nm

5.2 This is the correct formula for the error calculation: $\delta\Delta\lambda = |d\Delta\lambda/d\lambda| * \delta\lambda + |d\Delta\lambda/d\Delta z| * \delta\Delta z = 2 * \lambda/\Delta z * \delta\lambda + \lambda^2/\Delta z^2 * \delta\Delta z$