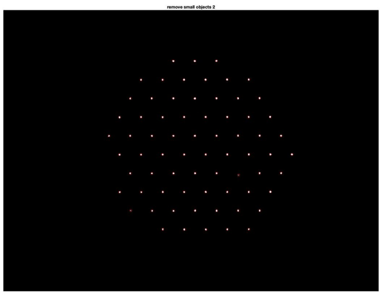
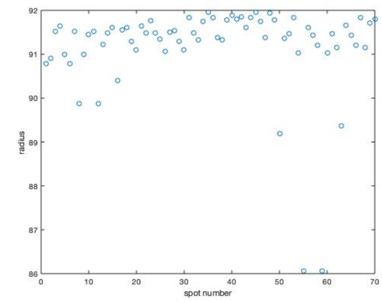
Shack Hartmann wavefront sensor

5. Summary of tasks of the experimental work

4.3 Calibration with point source at "infinity" (45 min)

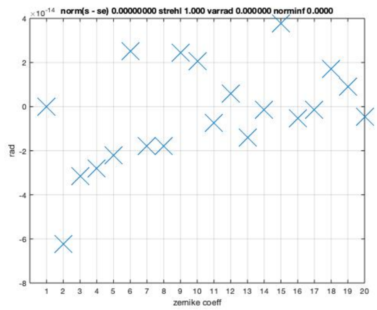
Run through the calibration procedure and plot the following images of **YOUR** calibration: Figure 20 c) (red circles that should not overlap), Figure 21 c) (size of dots that should be as uniform as possible, look at the scale).

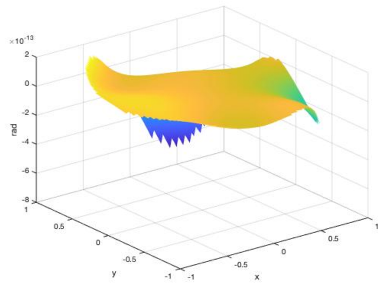




In the first image, it is hard to see because the image is very good, but there are small red circles in each spot of light. So, as required, they do not overlap.

Make measurement of the image used for calibration and present images as shown in Figure 23, the Zernike coefficients and the wavefront.





Calculate the maximum wavefront deviation with equation 5 (use your own values of course).

$$\Delta\phi[um] = \Delta\phi[rad] \cdot \frac{\lambda}{2\pi} = 6 \cdot 10^{-14} \cdot \frac{635 \cdot 10^{-9}}{2\pi} = 6.3 \cdot 10^{-15}[um]$$

Comment about the quality of your calibration!
The calibration is excellent, we have an error that is so close to zero it is hard to get any closer due to the computational limits of matlab. It is normal, after all, we are comparing the image with itself.

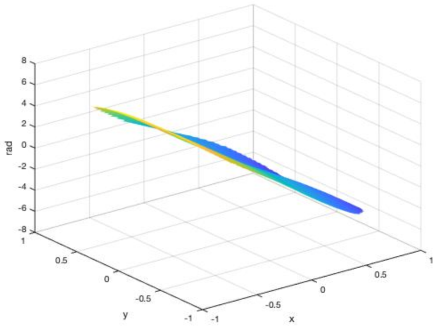
It is also a good first test, to see if the algorithm actually works, to compare the calibration image with its measurement and have no error as a result.

1.1

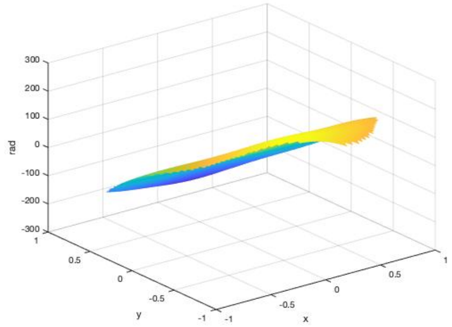
1.2

4.4. Measurement of tilts in different direction (30 min)

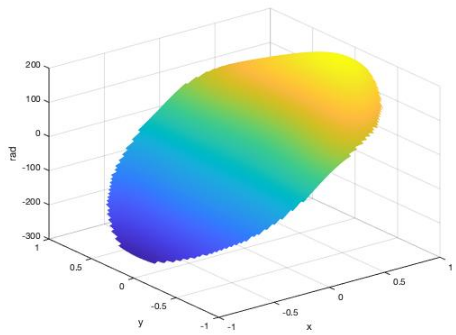
Measure the tilt in two different directions by using the Shack-Hartmann sensor. Give four images similar to those shown in Figure 24 for the situations: initial, maximum tilt (3/4 turns) in x and y direction and a control image when turned back to the original position.



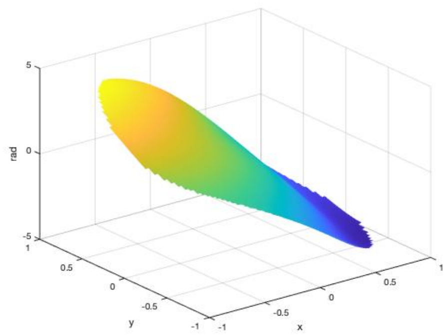
Initial



tilted in y direction at ¾ turns



tilted x direction at ¾ turns



control image

Establish a table with eight (8) measurements like shown below and fill in all numbers!
You need to use the equation below to calculate the wavefront shift in micron

$$\Delta\phi[um] = \Delta\phi[rad] \cdot \frac{\lambda}{2\pi} = \Delta\phi[rad]\frac{635 \cdot 10^{-9}}{2\pi} \approx 0.1 \cdot (\Delta\phi[rad])\ [um]$$

Image number	Tilt setting	Estimated maximum wavefront shift (rad)	Estimated maximum wavefront shift (micron)	Zernike coefficient X tilt (2)	Zernike coefficient y tilt (3)
1	0	14	1.4	-3.4	-0.1
2	¼ x	140	14	32	-1.2
3	½ x	320	32	81	-1.9
4	¾ x	420	42	114	-2.8
5	¼ y	171	17.1	-10	-48
6	½ y	323	32.3	-11	-88
7	¾ y	450	45	-8	-120
8	0	9	0.9	-2.1	1.1

Judge the quality of the tilt measurement!

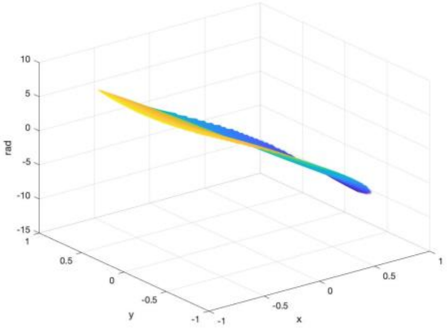
Generally, the logic is respected, the more we tilt, the greater is the wavefront shift and the greater are the Zernike coefficients that fit the polynomial characterizing that result. In this case the X tilt is linked to the second coefficient and the Y tilt is linked to the third coefficient.

We also note that because this is a handmade experiment, we have slight errors on the exact position and so we have a slight difference between the initial and control image which is acceptable. The magnitude of the coefficients is very low in both cases and we can assume those to be zero.

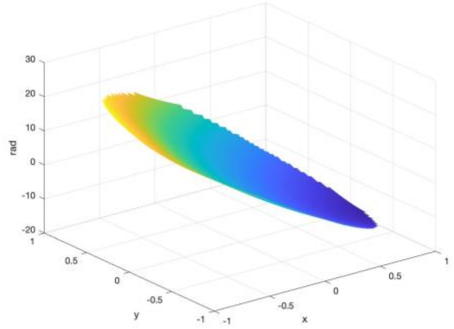
GROUP: NAME:

4.5 Measurement of different beam propagation characteristics (30 min)

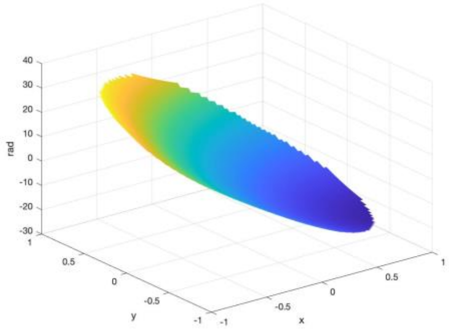
Establish a graph like Figure 26 and plot the 6 (six) images of the wavefront deviation.



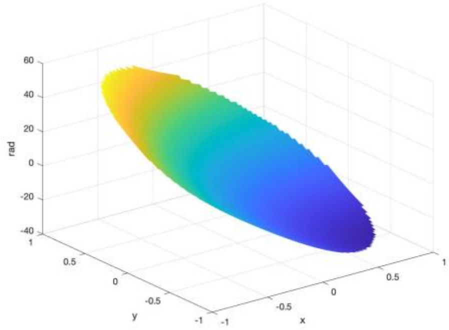
Initial



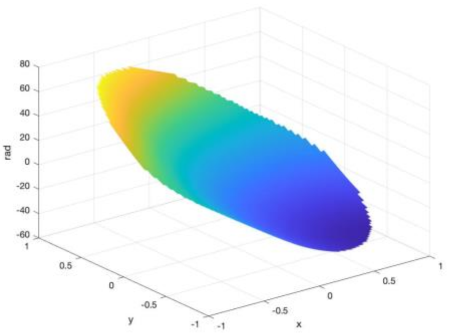
1 cm



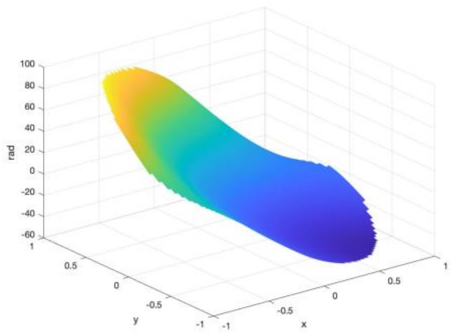
2 cm



3 cm



4 cm



5 cm

GROUP: NAME:

Make a table like shown below with all Zernike coefficients up to the 11th order.

Zernike coefficient	Description	0 cm	1cm	2cm	3cm	4cm	5cm
1	Piston	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
2	Tilt x	-5,02693	-9,50923	-11,64285	-15,71246	-19,28058	-26,41863
3	Tilt y	-0,53471	2,89963	7,26047	15,60764	22,13993	25,67954
4	Defocus - curvature	0,00623	1,92183	3,38320	5,23976	7,84326	10,37369
5	Astigmatism	0,03498	-0,07802	-0,07989	0,00379	-0,30175	-1,90204
6	Astigmatism	-0,27394	-0,46343	-0,46175	-0,22584	0,02051	0,53543
7	Coma y	0,03982	0,15824	0,11298	-0,04226	-0,37120	-0,76148
8	Coma x	0,09237	0,12391	0,15565	-0,07084	0,14084	-0,47974
9		0,20229	0,11427	0,03715	0,31635	0,42118	-0,56835
10		0,00680	-0,04614	-0,02617	-0,04522	0,46351	1,76390
11	Spherical - defocus	0,00509	-0,00417	-0,01523	-0,19289	-0,52949	-1,80460

Interpret the results for Zernike coefficient 4. Comment on the values for the coefficient 1,2 and 3.

The piston coefficient corresponds to the constant of the Zernike polynomial so it's normal that it is fix at 0 because we calibrate the system of this image at 0 cm.

The tilt and defocus coefficients increase when distance increases which is normal because we calibrate the system at relative distance of 0 cm so when moving the light source, the system is not calibrated anymore so the image is not focused anymore and is tilted. We can also interpret the coefficients with mathematical formulas where we see that they increase with distance and change with angle, where angle depends of distance.

mode j	order n	frequency m	$Z_n^m(\rho,\theta)$	Meaning
1	0	0	1	Constant term, or Piston
2	1	1	$2\rho\cos(\theta)$	Tilt in x-direction, Distortion
3	1	-1	$2\rho\sin(\theta)$	Tilt in y-direction, Distortion
4	2	0	$\sqrt{3}(2\rho^2-1)$	Field curvature, Defocus

Source :
https://moodle.epfl.ch/pluginfile.php/2737023/mod_resource/content/1/12%20Description%20Wavefront%20sensing%20%20Optical%20engineering%20-%2024.05.2019.pdf

4.6 Application example

Find an application example for a Shack Hartmann sensor and describe on ONE (1) page (including images and citations) its principle use and characteristics. TAKE CARE TO CITE THE IMAGES AND SOURCES CORRECTLY ESPECIALLY IF YOU USE WEB SOURCES.

The Shack Hartmann sensor is good for correcting image distortions/aberrations due to misalignments with the light source. If the source, be it our laser or a distant star, is not directly facing our detector, we'll want to correct that image. One way to do that is by deforming a MEMS mirror's surface to redirect the light. To do that we need to feed data to our controller for it to compute the tilt and correct the deviation. The resulting image on the detector will be of greater quality than that without the correction, allowing for better analysis.

The figure below illustrates that process:

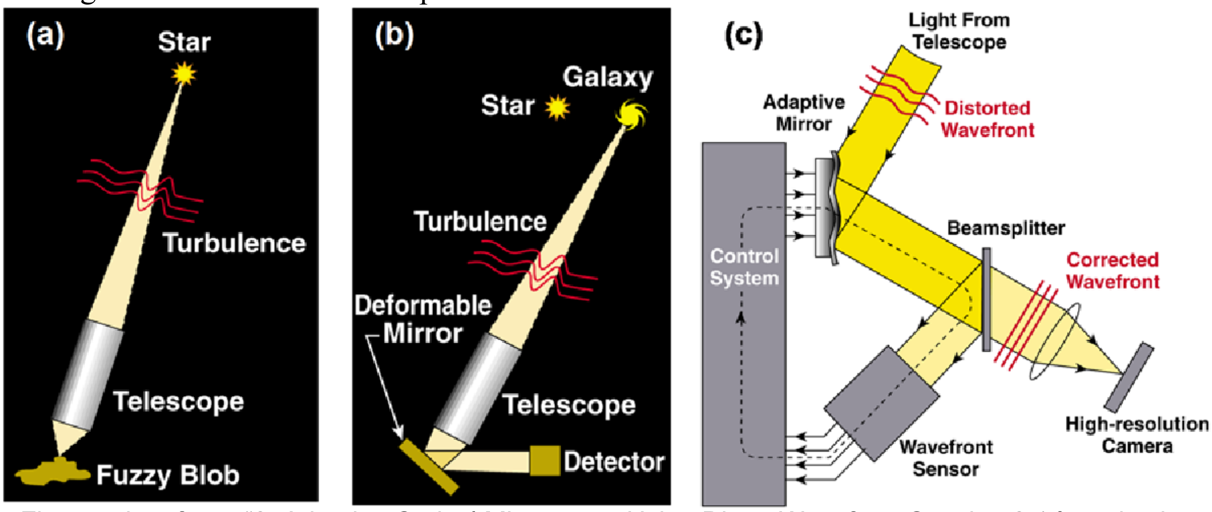


Figure taken from: "2. Adaptive Optical Microscopy Using Direct Wavefront Sensing 2.1 Introduction 2.2 Background 2.2.1 Wavefront Sensing & Correction in Astronomy Ao Has Been Used for Applications in Astronomy.".

Personal feedback:

Was the amount of work adequate? It was fine

What is difficult to understand? Not very

What did you like about it?
Amazed by the measurements we can make from a few dots.

How can we do better? By doing real TP ☺

Index of comments

1.1 Exactly, short and correct answer.

1.2 Přesně tak! Stručné a přesné vysvětlení ;).