Pupil Stabilizer

For centering the pupil in the nominal position the system use a loop. This loop use a the Hough Transform[1] for measure the center of pupil, then through an interaction matrix the loop calculate the command for the pupil motors.

The Hough Transform detects a circle of a determined radius processing an histogram in the parameter space, instead of the image space. The procedure is divided into 3 steps. The image is an average of 5 or 10 frames from the camera (248×256 pixels), rebinned by a factor 8 (31×32 pixels). The analyzed frames are made with about 3000 ADU per subaperture.

The first step is the edge-detection, we use the Sobel operator[2] that returns the edge ($\mathcal{S}$) and the edge orientation (θ) of an image.

A circle is defined by the equation $(x-a)^2+(y-b)^2=r^2$, the mapping from the image space (x,y) to parameter space (a,b,r)[1] is made by building an histogram($\mathcal{H}$). A pixel in the edge image $\mathcal{S}(\hat{x},\hat{y})$ contributes in the parameter space in the point $(\hat{a},\hat{b})$, where:

$$\begin{cases} a(x,y,r,\theta) & = x - r\cos(\theta(x,y)) \\ b(x,y,r,\theta) & = y - r\sin(\theta(x,y)) \end{cases}$$

$\mathcal{H}(a(x,y,r,\theta), b(x,y,r,\theta))$ is the sum of each pixel (x,y), mapped to (a,b), weighted by the values of the edge image $\mathcal{S}(x,y)$. The construction of the histogram is the second step, the third and last step is the analysis of the histogram through the fit with a gaussian peak. For a more robust procedure we repeat the analysis some times and each single analysis must be evaluated by some test on the width and the height of the gaussian peaks. In this way the procedures may evaluate the data and possibly discard it, for example in the case of absence of a star. Averaging the values the measurement accuracies improve, because of the imprecision of the single fit procedure.

The difference between the measured center and the target center is the centering error, if is substantial the the product with the interaction matrix give the command for the pupils motors. The interaction matrix is acquired moving the pupil motors and analyzing the related images.

In Table 1 shows the standard deviation of measure of the pupils center in four configuration, at Open loop and Close loop. The values are expressed in subapertures. The accuracies for the open and close loop are comparable comparable them, a difference is appreciable if we repeat the measures 2 or 3 times. For a good stabilization loop we need a measurement error less than 0.1 subapertures so the pupil stabilization loop based on the Hough transform is reliable.

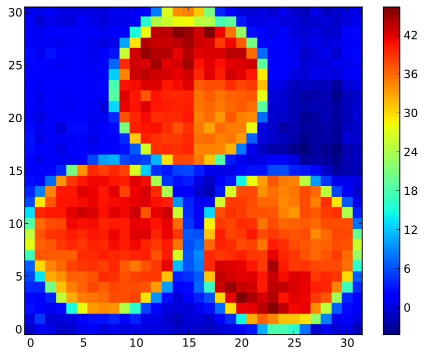
A test with the pupils overlapped it was done and the loop can return to the nominal position. A test with the aberrated pupils it was not done.

References

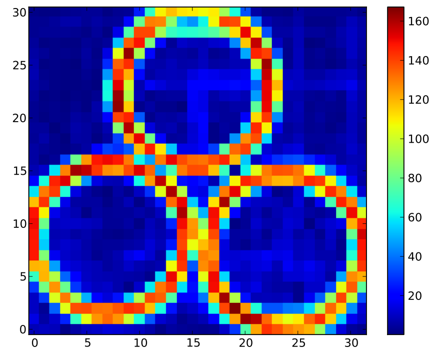
[1] D. H. Ballard. "Readings in computer vision: issues, problems, principles, and paradigms". In: ed. by Martin A. Fischler et al. 1987. Chap. Generalizing the hough transform to detect arbitrary shapes.

[2] Markus Hadwiger et al. *Real-time Volume Graphics*. 2006.

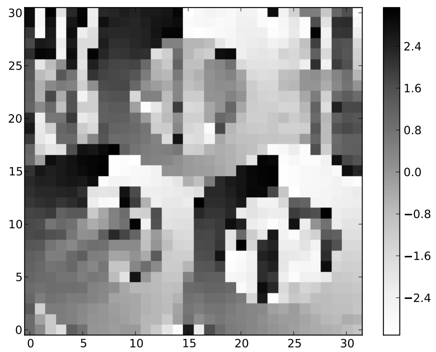
[1] In our case r is set to 7.5 subaperures



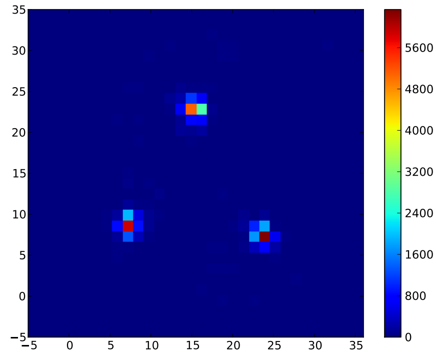
(a) Starting Image.



(b) Image convolved with Sobel operator, edge ($\mathcal{S}$).



(c) Image convolved with Sobel operator, edge orientation (θ).



(d) Hough transform of the image ($\mathcal{H}$).

Figure 1

Table 1: The performance of the measurement accuracy, calculated as the standard deviation and expressed in subaperures.

Loop	**# of cycle**	**# of images**	**# of measures**	**Axis**	**Blue**	**Yellow**	**Red**
Open	3207	10	3	x	0.017	0.009	0.013
				y	0.014	0.009	0.016
Close	2850	10	3	x	0.020	0.010	0.013
				y	0.021	0.010	0.015
Open	2782	5	2	x	0.022	0.013	0.017
				y	0.017	0.013	0.019
Close	9950	5	2	x	0.025	0.014	0.017
				y	0.025	0.013	0.017