Lens calibration for beam size monitors at ThomX

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Introduction

- Beam size meaurement is an important and necessary diagnostic feature of the ThomX injection line and beam dumps
- At each diagnostic station along the beamline a YAG screen, USAF1951 microscope resolution target, and blank screen are mounted on rails driven by a stepper motor, and can be driven into or out of the beam position. Digital cameras with Tamron telephoto lenses are mounted to observe the intended beam trajectory.
- Our work is to present methods for the automatic calibration of the camera and optical systems that observe the YAG screens
- We also will present work to repurpose readily available Canon EF mount autofocus capable lenses as a novel method for remotely controlled optical focusing system
- We note that our work makes heavy use of the OpenCV library [1]

Region Of Interest (ROI) detection

- First step is to isolate areas featuring only one target
- We use a method similar to and influenced by [2] based around morphological transformations
- The process is as follows:

1. Black hat transform used to highlight dark structures smaller than a given size
2. Image thresholded with combination of Otsu and distance map threshold
3. Opening and closing operations used to ensure rounded regular shapes, containing whole ROI plus border
4. We then search for complete blobs with connected components algorithm, and filter based on area, dimesional raio and other criteria

Software - process and testing

- To calibrate the cameras we must identify each target visible, and the largest and smallest elements of each target
- We first identify regions of interest that potentially contain at most one target
- We then further analyse these regions, identifying the visiable USAF1951 groups and elements
- To assess the stability of the software, we tracked elements inside the image using the software as we moved the target in constant increments - see 5

ROI analysis

- ROI is binarised and potentially Fourier filtered
- Orientation of image estimated by looking at histogram/KDE of gradient directions in image; due to regular rectangular shapes, orientation has a clear peak
- Individual shapes are then found by connected components algorith, their size measured, and the filtered based on area, dimensional ratio, and closeness to image orientation
- Individual shapes are then clustered based on position, size, and orientation. Each cluster corresponds to a USAF1951 element
- The smallest element seen is used to measure the optical system resolution for this ROI, and the largest used to estimate the transformation from pixel coordinates to laboratory coordinates.

Pictures

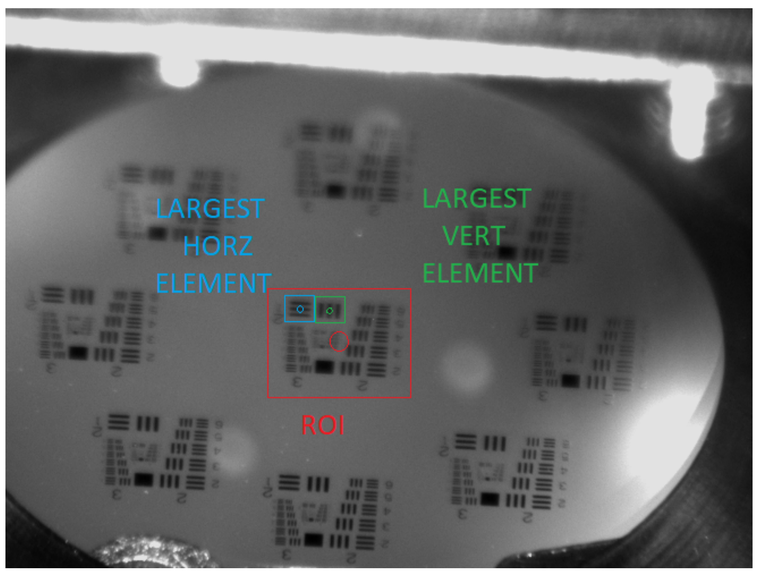

Fig. 1: Image to be analysed

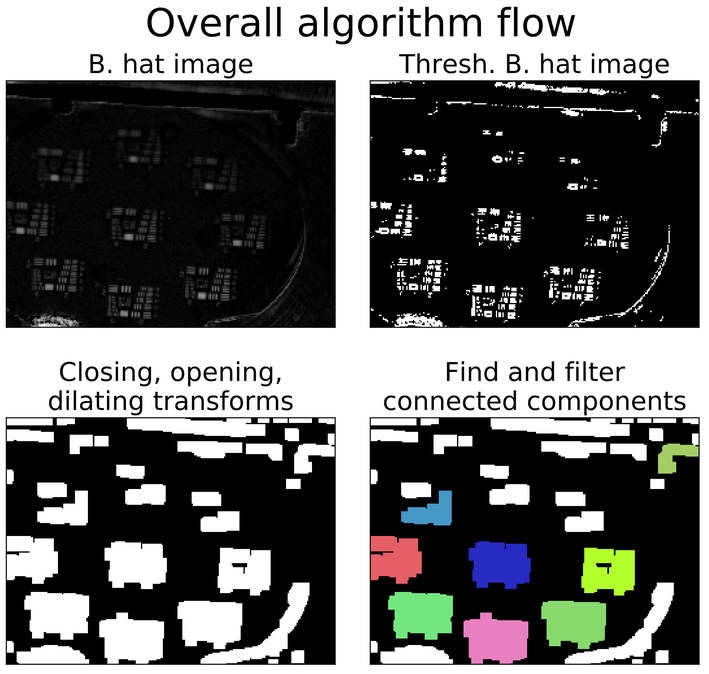

Fig. 2: ROI detection through morphological operations

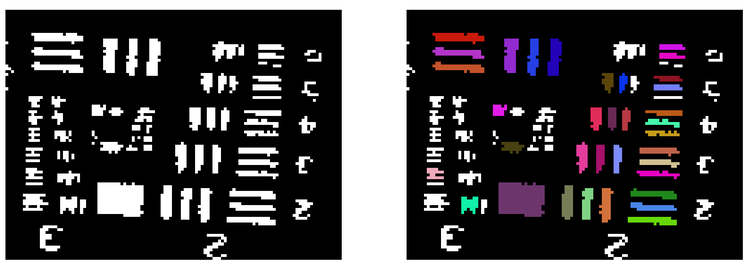

Fig. 3: Binarised image, and image showing filtered connected components

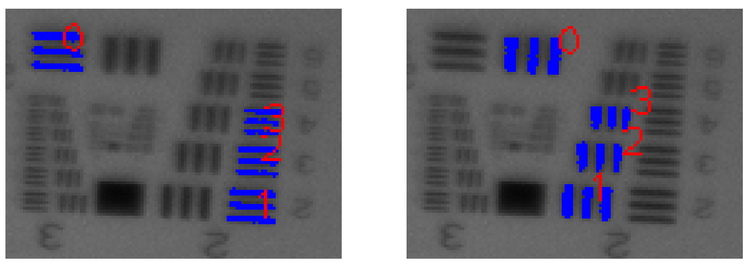

Fig. 4: After clustering similarly sized and located horizontally or vertically oriented elements

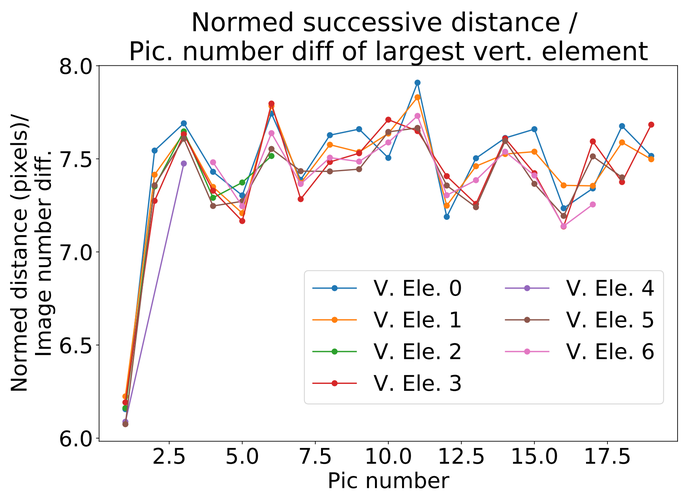

Fig. 5: Test of software stability - tracking largest vertical element

Nomenclature

- To aid discussion, the following terms are used:

USAF1951 test chart The entire glass slide

Target A set of groups in a spiraling shape. There are nine targets on each of our USAF1951 test charts

Group A set of six elements of different size. From largest to smallest in a group, the sizes differ by a factor $2^{-\frac{1}{6}}$

Element A pair of two bar patterns of same size but differing in rotation by 90 degrees

Bar pattern A set of three bars of the same orientation

- Other terms may be used elsewhere
- An example image may be seen in figure 1

Novel remote controlled optical system using readily available Canon EF mount lenses

- Canon EF mount lenses are readily available, and when attached to a camera body are able to precisely autofocus
- By repurposing the lens motor control, we are able to control the focus of the lens
- We can then use software autofocus algorithms (such as [3]) and lens motor control to focus images automatically

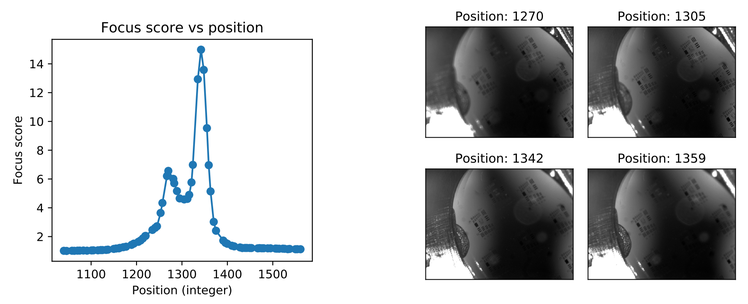

Fig. 6:

- In figure 6 we present results of scanning an image using an image sharpness score from [3]. The large peak corresponds to focusing on the USAF1951 microscope chart, the secondary peak corresponds to focusing on the diagnostic station porthole.
- We plan to use image masks to ensure we only focus on the USAF1951 chart

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References

[1] G. Bradski. "The OpenCV Library". In: *Dr. Dobb's Journal of Software Tools* (2000).

[2] Melinda Katona and László G Nyúl. "A novel method for accurate and efficient barcode detection with morphological operations". In: *2012 Eighth International Conference on Signal Image Technology and Internet Based Systems*. IEEE. 2012, pp. 307–314.

[3] Feimo Shen, Louis Hodgson, and Klaus Hahn. "Digital autofocus methods for automated microscopy". In: *Methods in enzymology*. Vol. 414. Elsevier, 2006, pp. 620–632.