Research Internship: Zoe @ Matterhorn Studio

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## Facts and Details

**Project:** Machine Learning for Optimising Laser Beams with Deformable Mirrors, specifically with Bayesian Optimisation

**Time**: In a first instance, part-time, 2nd May to 31st of May (22 working days), or full-time (or anywhere in between). Full-time would probably require you to pause all your tutoring, so I’d strongly recommend part-time for the trial! A possible extension to be determined 29th of May!

**Salary**: Standard UK PhD Full-time Stipend: £17668/year; £1473/month; £19668/year if in London, £1,639/month (<https://www.ukri.org/what-we-offer/developing-people-and-skills/find-studentships-and-doctoral-training/changes-to-the-minimum-stipend-from-1-october-2022/>)

## Specific steps

* Characterise beam quality with e.g. Gaussian Mixture Models, specifically variational GMM
  + <https://scikit-learn.org/stable/modules/mixture.html#variational-bayesian-gaussian-mixture>
* Optimise beam quality with Bayesian Optimisation by reducing number of peaks identified by vGMM
  + <https://www.youtube.com/watch?v=c4KKvyWW_Xk>
  + <https://machinelearningmastery.com/what-is-bayesian-optimization/>
  + <https://arxiv.org/abs/1807.02811>
* Most likely, things won’t be that easy, so let’s be flexible

## Outcomes

* Jakob: evaluate Zoe’s fit, evaluate potential of suggested method, evaluate possible extension of internship
* Zoe: evaluate fit with Jakob, evaluate fit with this kind of ML work, build a showcase example for Matterhorn website(try to simplify the whole process and let laypersons have a quick experience of ML techniques) ,learn more Machine Learning methods: Gaussian Process, Bayesian Optimisation, Gaussian Mixture Models

## Definition of “success”:

We should more carefully define some specific test cases to aim for.

* E.g. ability to identify an arbitrary number of local maxima (say between 1 and >5) in a focal spot image as a quality metric. Focal spot images can be “noisy” so we also need to test against “pathological” over counting of noise as an apparent maxima.
* Comparison of new quality metrics against software tools Zoe has already developed during her Masters project, are these new tools faster, more accurate ?
* Test of one or more new method (focal spot quality metric and / or optimisation algorithm) on a physical test system with a 9-actuator DM and an aberrated focal spot.

## Resources:

* What specific resources are required to allow the project to progress, what fraction should be based on pre-recorded data sets (e.g. focal spot images) versus access either in person or remote to real world hardware ?
  + In a first step, we should be able to test the machine learning methods based on pre-recorded datasets. Then, whenever the real setup is available, move to that and test there.
  + Zoe: For the first step about the new potential quality metric, external resources are not necessary. I could use my old image data first. For the second step about the Bayesian optimisation, it will need the closed-loop set up in the lab so laser, 2DMs(could be 5-5 or 5-9 or 9-9), Thorlab Camera, cables, etc.
* Is Zoe still able to access Imperial College via VPN ? If so we should set up a lab based test system she can access to run some of the work remotely. If not, we will have to come up with an alternative solution to remote access to lab hardware.
  + Zoe: It seems that my old school account is no longer accessible to Imperial’s remote desktop, but I could use my personal VPN to connect a PC remotely, just like how I did in my project before. Need to access lab first to set all up.
* Question for Zoe, what “old” data sets do you still have access to. Lets document number of images, image size, some kind of description of the mix of “good” and “bad” images.
  + Zoe: Lots of image data(around 80k), saved with the exact PWM values assigned to them, from “good” to “bad”.
* Lets define some new test data sets to generate. What specifically do we want, examples with multiple maxima for example ?
  + Jakob: From an ML perspective, anything that’s realistic to occur in the real setup is relevant, and I assume that includes multiple maxima!
  + Zoe: could try to generate multi-maxima image and see how the new quality metric with multi-peak compared with others.
* Mirror systems, I suggest we begin with a 9 actuator DM system as we have several of these “live” at the moment and Zoe will be familiar with running them. This also provides a well defined starting point for benchmarking new algorithms against tools Zoe developed during her masters project.
  + Jakob: Sounds good! 9 dimensions does exponentially increase the convergence time for Bayesian Optimisation, but I think we should still be fine.
  + Zoe: could do and take more data image with 9
* 15 actuator system. This needs a bit more work before it is usable, unfortunately RAS is the limiting factor here as we are moving into exam marking seasons so I have lots of demands on my time right now.
  + Jakob: I assume RAS is Roland Smith!
* List of data set:
  + 80k\*focal spot images with fixed aberrations (exact PWM values)
  + 100\*static aberrations of increasing severity
  + Image type: png
  + Image size: 600x600 pixels.
  + Camera type (Thorlabs CCD)
  + Number of nominally identical repeats of each example (it varies)
* Thoughts on priorities: the first lab data needed might be multi-peak images generated, then try the new algorithm with Bayesian.

## Documenting the work:

* How will the work be documented ? Zoe should run a lab book documenting what she attempts to do, we also need to be able to archive data sets, e.g. focal spot images, code.
* Set up one-notes and provide access to other team members.
* Set up Github for code samples and version control.
  + I have started a Github here provisionally and can add people, but zoe you can start your own and add me ‘jakobzeitler’
    - <https://github.com/jakobzeitler/deform_mirrors_zoe>
  + Zoe: It seems that the link is 404 for me. I just created a new one. Roland may I have your GitHub username or email to invite you to access?

## Project Supervision Meetings

* We need to define how the project will be managed and how progress will be monitored, suggestions fed into the work and outputs discussed. Suggest weekly Teams meeting, say Mondays 11-12 ?
  + Jakob: Mondays 11-12 works for me.
  + Zoe: I am available with any time slots in Monday or Tuesday.