Elettra Sincrotrone Trieste

Reinforcement Learning for FEL performance optimization
- My Experience -

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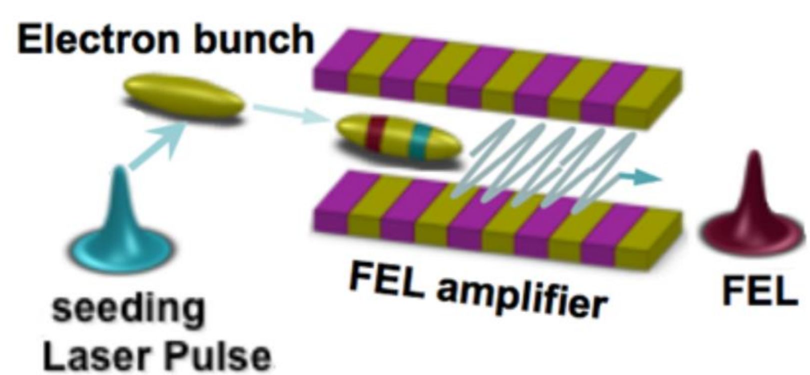
FERMI:
Seeded Free-Electron Laser

Free-Electron Laser (FEL): IV generation light source

- Radiation generated by the interaction between a relativistic electron beam and a magnetic structure

Seeded FEL: electron bunch modulated in energy by seed laser

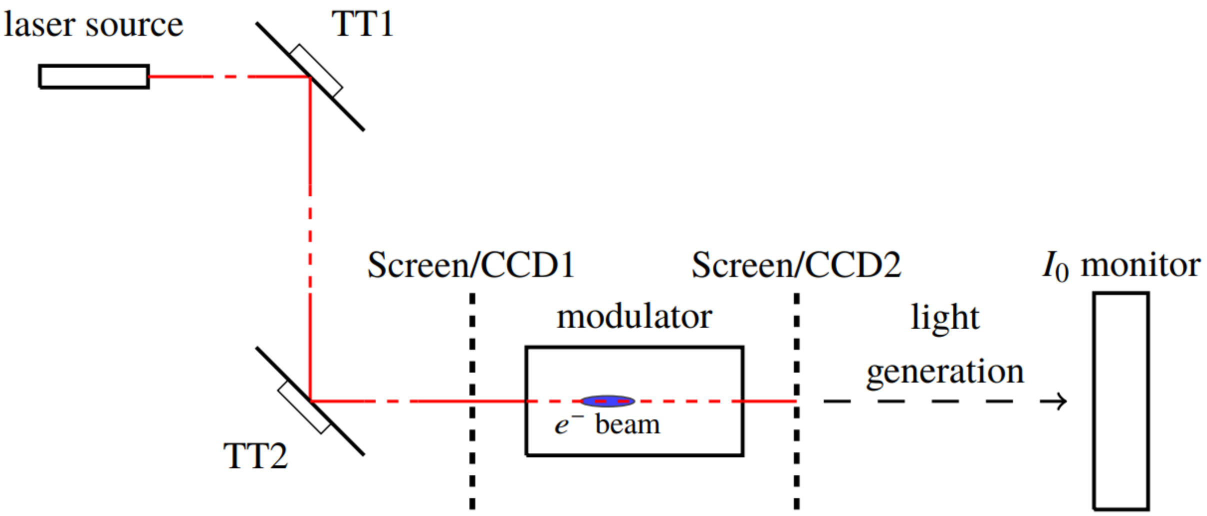


Seed Laser Alignment System

A standard optical alignment system consist in:

- 2 planar Tip-Tilt mirrors (TTs) each one paired with 2 piezo-motors
- 2 screens based on Charge-Coupled Devices (CCDs)

Seed laser simplified scheme



Analytical model of the simplified system

→ Simulated environment in MATLAB for off-line tests

RL Algorithms & MATLAB

Considered RL algorithms:

- **SARSA(λ)**
- **Q-learning**

} *Tabular* and with *Linear Function Approximation*

General details:

- $\varepsilon - greedy$ *policy*
- *Potential-Based Reward shaping* $F(s,s') = \gamma\Phi(s') - \Phi(s)$
- *Gaussian Radial Basis Functions* (RBFs) as Lin. Func. Approx.

All algorithms have been implemented in MATLAB

Reinforcement Learning Toolbox was not already released

RL Algorithm for real tests

Q-learning with Linear Function Approximation (LFA)

- Q-learning approximates the optimal action-value function Q^*
- LFA maps a discrete state space into a continuous one

  Parametric form $Q(s,a,\theta) = \theta^T\varphi(s,a)$ using Gaussian RBF

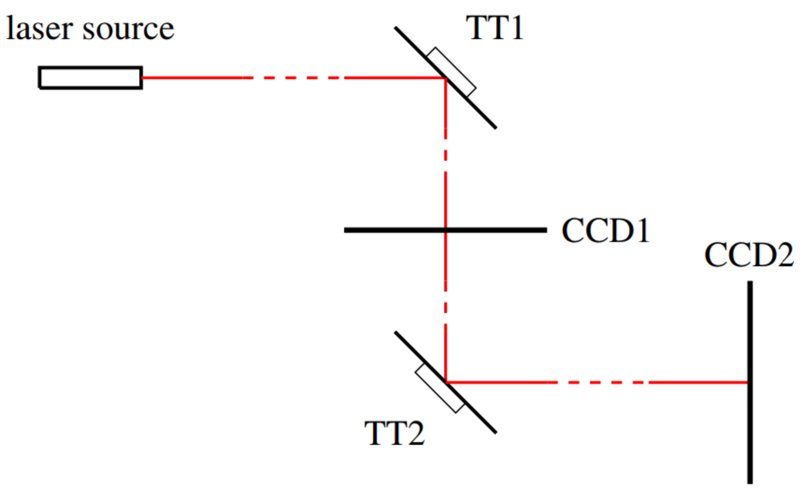
Chosen for:

- Lower number of hyper-parameters with respect to SARSA(λ)
- More adaptable to real systems than *Tabular* algorithms

Electro Optical Sampling (EOS) Service Laser

Service Laser of the EOS station:

- Alignment scheme similar to the seed laser
- Often available → 10 runs (# episodes: Training 300 + Test 100)
- More time consuming than simulator
- Code debugging on safer system



EOS laser simplified scheme

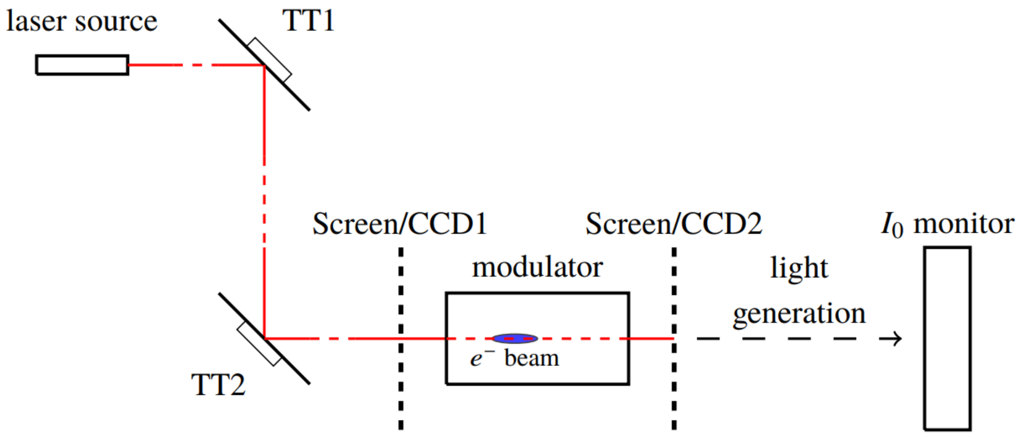
Intensity measured in Region of Interest (ROIs) on CCDs

FERMI FEL - Seed Laser

FERMI Seed Laser:

- Challenging hyper-parameters setting
- Hardly available → 1 runs (# episodes: Training 300 + Test 50)
- Higher noise in measurements
- Drifts

Seed laser
simplified scheme

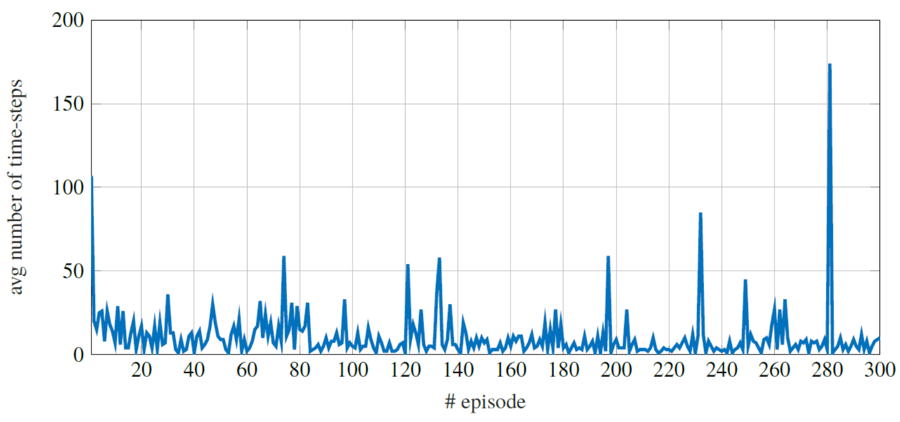


FERMI FEL - Results

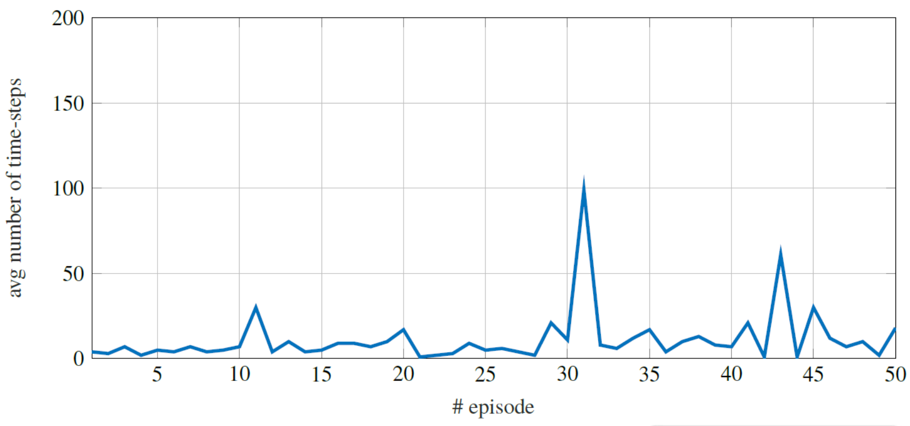
Intensity: measured by the I_0 monitor

Episode stops if
- Intensity Target, I_T, is reached
- max num of steps is reached

Training Phase

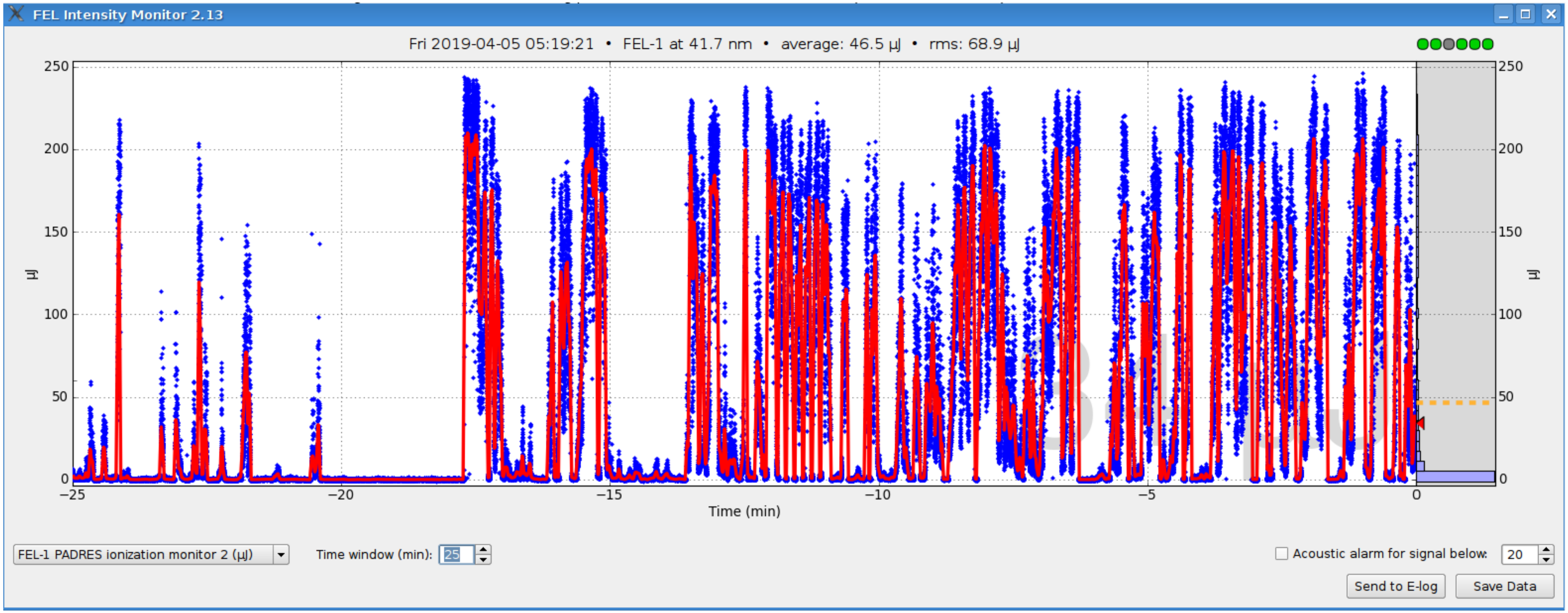


Test Phase



FERMI FEL – Results I_o monitor

FEL intensity in the first 25 minutes of the training phase



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Results Discussion

- Exploration in first episode is sufficient to easily reach target in next episodes

- Peaks in Tests:

  I. Machine drifts

  II. Improper setting of :

  → k *(reward shaping hyper-parameter)*

  → R *(reward) during training*

  } Tuning to balance between these values in successful episodes

Further analysis will be carried out in future works

Future Developments

PYTHON implementation of:

- Deep-Q-Network (DQN), variant of Q-learning algorithm

  → Learning directly from images of the FEL spectrum

- Policy Parametrization

  → Continuous actions

Lessons Learned & Open Questions

- Why developing RL code from scratch in MATLAB?
  - Best initial personal knowledge
  - RL Toolbox was not already released
  - Very valuable experience of understanding the internals of RL

- Why RL instead of other optimization methods (i.e. Gradient Descent, Nelder Mead, Extremum Seeking, ...)?
  - Global vs Local optima
  - Memory of previous experience

- Weak points of RL
  - Time consuming
  - Problem of machine drifts
  - Delicate definition of hyper-parameters

Thank you!

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