FJPPL (TYL) application 2020-2021

Fiscal year April 1st 2020 – March 31st 2021

Please replace the red examples by the appropriate data in black

ID[1]:	Title: Advanced optimization algorithms and neural networks for accelerators control					
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Advanced control and optimization techniques for accelerators

Accelerator related topics:

- Tuning/optimization/control
- Data analysis
- Simulation/modeling
- Prognostics/alarm handling/anomaly-breakout detection

&

ML Techniques :
Supervised Learning (Regression, Classification) ,
Unsupervised Learning (Clustering,
Dimensionality reduction),
Reinforcement Learning.

The **goal** of our project is is to investigate and demonstrate the use of ML techniques for advanced control and performance optimization of the accelerators and, in particular, the KEK injector.

Improving accelerators:

- machine tuning and beam dynamics, beam parameters extraction, dealing with noisy data;
- diagnostics and control of high intensity laser
- virtual detectors for machine monitoring purposes
- use data more efficiently

Conferences, papers, workshops, discussions

Machine Learning for Orders of Magnitude Speedup in Multi-Objective Optimization of Particle Accelerator Systems

Auralee Edelen[1], Nicole Neveu[1], Matthias Frey[2], Yannick Huber[2], Christopher Mayes[1], Andreas Adelmann[2]

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MACHINE LEARNING METHODS FOR OPTICS MEASUREMENTS AND CORRECTIONS AT LHC

E. Fol*, F. Carlier, J. Coello de Portugal, A. Garcia-Tabares Valdivieso, R. Tomás
CERN, Geneva, Switzerland

Abstract

The application of machine learning methods and concepts of artificial intelligence can be found in various industry and scientific branches. In Accelerator Physics the machine learning approach has not yet found a wide application. This paper is devoted to the evaluation of machine learning methods aiming to improve the optics measurements and corrections processes at LHC. The main subjects of the study are the detection of faulty beam position monitors and the prediction of quadrupole errors using decision trees and artificial neural networks. The results presented in this paper clearly show the suitability of machine learning methods for the optics control at LHC and the potential for further investigation on appropriate approaches.

FAULTY BPMS DETECTION USING CLUSTER ANALYSIS

The phase of measured betatron oscillation is inferred from a harmonic analysis of the turn-by-turn transversal beam positions measured at BPMs around the ring. Reconstruction of the optics is mainly concerned by the propagation of phase advances between BPMs [4]. Therefore, the appearance of a faulty signal has significant impact on the obtained optics functions and sequentially computed corrections. In this work we evaluate faulty BPM signal detection applying cluster analysis. Cluster analysis includes methods of grouping or separating data objects into regions in a hyperparameter space, such that dissimilarity between the objects within each cluster is smaller than between the

Advanced Control Methods for Particle Accelerators (ACM4PA) 2019*

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(Dated: January 16, 2020)

Los Alamos is currently developing novel particle accelerator controls and diagnostics algorithms to enable higher quality beams with lower beam losses than is currently possible. The purpose of this workshop was to consider tuning and optimization challenges of a wide range of particle accelerators including linear proton accelerators such as the Los Alamos Neutron Science Center (LANSCE), rings such as the Advanced Photon Source (APS) synchrotron, free electron lasers (FEL) such as the Linac Coherent Light Source (LCLS) and LCLS-II, the European X-ray Free Electron Laser (EuXFEL), the Swiss FEL, and the planned MaRIE FEL, and plasma wake-field accelerators such as FACET, FACET-II, and AWAKE at CERN. One major challenge is an the ability to quickly create very high quality, extremely intense, custom current and energy profile beams while working with limited real time non-invasive diagnostics and utilizing time-varying uncertain initial beam distributions and accelerator components. Currently, a few individual accelerator labs have been developing and applying their own diagnostics tools and custom control and ML algorithms for automated machine tuning and optimization. The goal of this workshop was to bring together a group of accelerator physicists and accelerator related control and ML experts in order to define which controls and diagnostics would be most useful for existing and future accelerators and to create a plan for developing a new family of algorithms that can be shared and maintained by the community.

PASJ2019 THPH007
July 31 - August 3, 2019, Kyoto, Japan

機械学習を使用した KEK Linac 加速器運転調整システムの開発

R&D OF THE KEK LINAC ACCELERATOR TUNING USING MACHINE LEARNING

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Abstract

We have developed an accelerator parameter tuning scheme using machine learning for the KEK e^-/e^+ injector linac (Linac). During the accelerator operations, various parameters are continuously optimized to get the high injection efficiency. To get more efficient and faster tuning scheme, and to improve the injection efficiency, we have designed a new accelerator tuning scheme by introducing the machine learning. The R&D for the new scheme is based on the accumulated Linac operation data (control parameters, monitoring data, environmental data), to see correlations between the injection efficiency and various accelerator parameters. In this paper, we report the current status of the study.

Opportunities in Machine Learning for Particle Accelerators

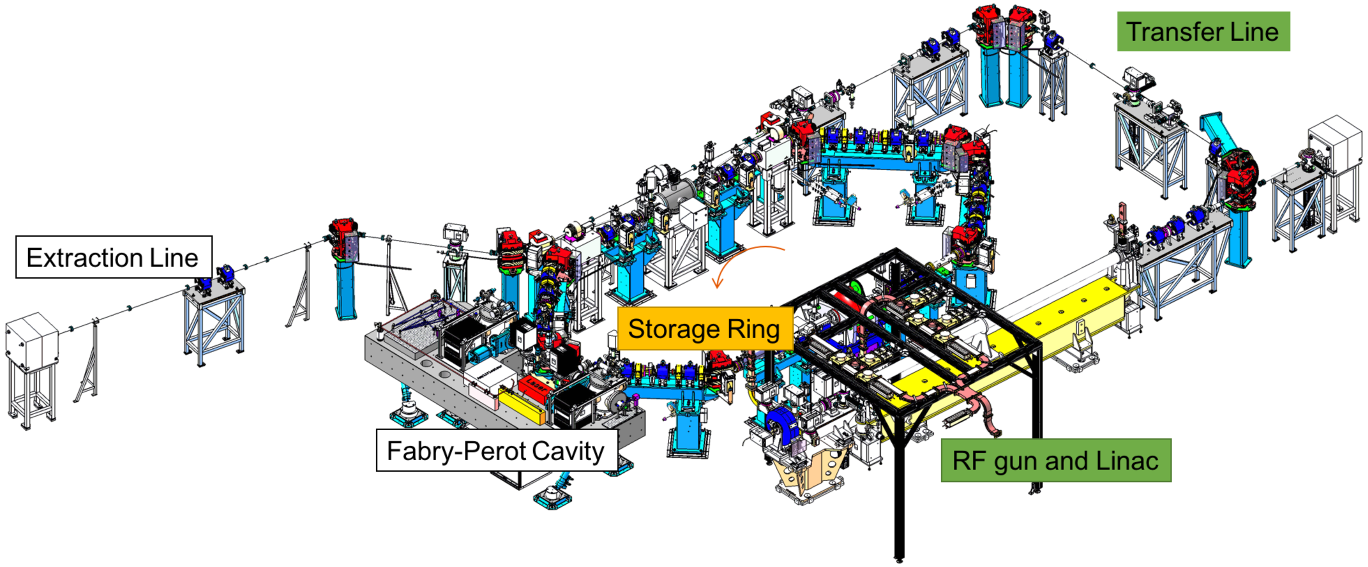
Auralee Edelen, Christopher Mayes, Daniel Bowring, Daniel Ratner, Andreas Adelmann, Rasmus Ischebeck, Jochem Snuverink, Ilya Agapov, Raimund Kammering, Jonathan Edelen, Ivan Bazarov, Gianluca Valentino, Jorg Wenninge

(Submitted on 7 Nov 2018)

Machine learning (ML) is a subfield of artificial intelligence. The term applies broadly to a collection of computational algorithms and techniques that train systems from raw data rather than a priori models. ML techniques are now technologically mature enough to be applied to particle accelerators, and we expect that ML will become an increasingly valuable tool to meet new demands for beam energy, brightness, and stability. The intent of this white paper is to provide a high-level introduction to problems in accelerator science and operation where incorporating ML-based approaches may provide significant benefit. We review ML techniques currently being investigated at particle accelerator facilities, and we place specific emphasis on active research efforts and promising exploratory results. We also identify new applications and discuss their feasibility, along with the required data and infrastructure strategies. We conclude with a set of guidelines and recommendations for laboratory managers and administrators, emphasizing the logistical and technological requirements for successfully adopting this technology. This white paper also serves as a summary of the discussion from a recent workshop held at SLAC on ML for particle accelerators.

Example 1: THOMX project at IJCLAB (discussed here)

ThomX - Compact source of X-rays
Producing a compact source of directional X-rays, with high performance, very bright, monochromatic and with adjustable energy for application to the field of medical science (imaging and therapy) and social science (artistic heritage), technology and industry.



- **Linac and transfer line:** find day to day repeatable beam conditions
  is challenging task (temperature conditions, laser jitter, …). Reproducible beam dynamics. Injection matching with Ring.

- **Ring:** Need to stabilize machine, find stable orbit.
  First turns – need to match several parameters.
  There are empirical ways. Machine expert can do (experience).
  We search for automatization/ guiding. Study case.

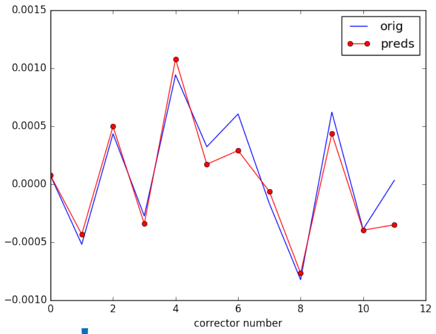
Waiting for ASN permission to start

Example 2: KEK LINAC (similar ML approach, less discussed here due to the limitation of number of slides)

RING: Study case. Some details.

Single particle Trajectory (several turns):

1. Control parameter: Corrector magnets. 12 independent variables in transverse horizontal/vertical planes.
2. Physics simulation. Accelerator Toolbox (MATLAB).
3. Measured: trajectory/n-turns/orbit represented by 120 variables (12 BMPs x 10 Turns).

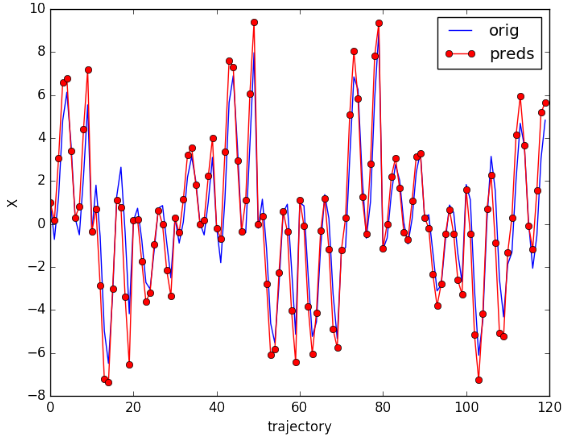


INPUT Correctors → Physics Simulation → **OUTPUT** Trajectory

Supervised learning:

1. Prepare vectors of corrector and calculate corresponding trajectories.
   MATLAB Engine API for Python.
2. Train model to predict correctors based on the trajectory input.
   XGBRegressor + MultiOutputRegressor, NN, Jupyter notebook at server 48 threads ~ 1 hour.

measured
predicted Trajectory



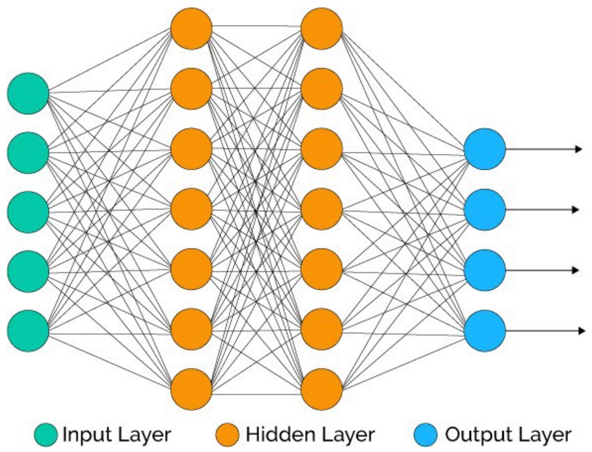
INPUT Trajectory → ML model → **OUTPUT** Correctors

Correctors

In real life: noise in measurements, BPM readings at low statistics not so good, etc.
Once orbit is found: large statistics allows to use well developed methods in accelerator physics (SVD, optimization, etc.).

Typical workflow

1. Formulation of the problem
2. Preparing dataset and “understanding of the data”
3. ML model: development, training, improvement



Ongoing studies:
- prediction of correctors magnets currents
- Trajectory minimization
- Noise “filtering” in the data
- Model robustness
- Beta function reconstruction from TBT data
- Optimization of injection
- Orbit classification
- Failure/anomaly detection
- Inverse problems

Methods:
NN, CNN, XGBoost

Tools:
Jupyter notebook, Keras, pytorch

Hardware:
Mainly CPU

Discussion

- Accelerator physics could strongly benefit from machine learning tools.
  Outcomes: very precise control of parameters and machine stability.

- Tests of the models on the live data from the accelerator and analysis of the improvements of the linac performance. The predicted parameters then could be inserted to the EPICS data channel for the monitoring purposes. In such a way, we will explore/validate ML concepts for possible generalization and application for particle accelerators

- This project allows strengthening the collaboration between our groups on these items by personnel exchanges via travels to the French laboratory IJCLab and KEK, where the commissioning of the SuperKEKB accelerator complex is currently ongoing.