First experiences with machine learning techniques at the 1.5 GeV synchrotron light source DELTA

D. Schirmer
Center for Synchrotron Radiation (DELTA), TU Dortmund University, Germany

Recently, artificial intelligence (AI) has experienced a renaissance in many fields. AI-based concepts are nature inspired and can also be used in the field of accelerator controls [1-23]. At DELTA various studies on this subject have been carried out in the past [2-4]. Due to increasing computing performance and great advances in theoretical AI research as well as the availability of powerful AI programming frameworks [7-11], this studies again met great interest and could be continued successfully. Among other possible applications, the use of neural networks for automatic correction of the electron beam position (orbit control) is of interest. Machine learning (ML) simulations with a DELTA storage ring model were already successful [3]. Recently, conventional Feed-Forward Neural Networks (FFNN) were trained on the basis of real machine data in order to carry out local and global beam position corrections in the 1.5 GeV storage ring Delta. This net was trained with two response matrices (BPM readings for positive and negative single steerer kicks) and 1500 arbitrary orbits, generated by randomly distributed steerer kicks [+/- 200mA] and booster, a booster transfer line (T1) between linac gun, followed by a linear accelerator (70MeV), a first transfer line (T2) connecting the booster and the storage ring (1.5GeV). Three insertion devices (U250, U55, SAW) generate dedicated synchrotron light in various wavelength ranges.

The global orbit correction system of the 115 m long storage ring is composed of 54 beam position monitors (BPMs), 30/26 horizontal / vertical corrector magnets (approx. 1Hz). In addition 19/21 fast steerer (1kHz) and 30/26 slow steerer (1Hz) magnets can be used for fast orbit correction (some 100Hz) [22]. Orbit monitoring and correction is an important task in accelerator controls. At DELTA, SVD-based (singular value decomposition) orbit correction programs have been successfully used in routine machine operation for many years [13-15]. Currently, a new “Cone-Program”-based approach to orbit correction is being evaluated [16]. Another concept applies artificial neural network (ANN) techniques [17,18]. First prototype studies were carried out with the Matlab programming workbench and corresponding toolboxes [11, 20, 21].

The DELTA accelerator facility consists of a 90keV electron gun, followed by a linear accelerator (70MeV), a first transfer line (T1) between linac and booster, a booster synchrotron (70MeV to 1.5GeV), a second transfer line (T2) connecting the booster and the storage ring (1.5GeV). Three insertion devices (U250, U55, SAW) generate dedicated synchrotron light in various wavelength ranges.

The global orbit correction system of the 115 m long storage ring is composed of 54 beam position monitors (BPMs), 30/26 horizontal / vertical corrector magnets (approx. 1Hz). In addition 19/21 fast steerer (1kHz) and 30/26 slow steerer (1Hz) magnets can be used for fast orbit correction (some 100Hz) [22].

The DELTA storage ring is composed of 54 beam position monitors (BPMs), 30/26 horizontal / vertical corrector magnets (approx. 1Hz). In addition 19/21 fast steerer (1kHz) and 30/26 slow steerer (1Hz) magnets can be used for fast orbit correction (some 100Hz) [22].

The global orbit correction system of the 115 m long storage ring is composed of 54 beam position monitors (BPMs), 30/26 horizontal / vertical corrector magnets (approx. 1Hz). In addition 19/21 fast steerer (1kHz) and 30/26 slow steerer (1Hz) magnets can be used for fast orbit correction (some 100Hz) [22].

The six essential steps from data acquisition to the application of neural networks. In particular, the quality of data mining and preparation (e.g. data cleaning) plays a significant role in machine learning.

Supervised Learning
- neural network training
- network training
- network testing
- network validation
- network deployment

Neuron Model
- input
- connection weights
- bias terms
- output

Network Topology
- input layer
- hidden layer
- output layer

NN Development Stages
1. data sources/acquisition
2. data cleaning
3. training/learning
4. testing/evaluation
5. performance check
6. testing

Feed-Forward Neural Net (FFNN) with approx. 1500 measured machine data records (orbit/steerer-data sets). Best validation performance (mse) of 2.7*10^-10 was reached after 96 BR-training iterations of all records.

Comparison of different computing methods: Single Value Decomposition (SVD) [13, 15], qcone-based (convex optimization) [16] and machine learning based (FFNN), lead to comparable results after multiple successive correction steps.
References

[15] E. Meier, Y. F. Tan, G. S. Lefebvre, "Orbit Correction Studies Using Neural Networks", in Proc. IPAC'12, New Orleans, Louisiana, USA, pp.237-2389.
[16] D. Schirmer et al., "Control System Projects at the Electron Storage Ring DELTA", in Proc. ICAP'17, Barcelona, Spain, pp.1351-1355.
[18] "Experience with machine learning in accelerator controls", in Proc. ICAP'17, Barcelona, Spain, pp. 258-264.
References

NN R² Results for FFNN2: Regression R Values measure the correlation between "h23r" sleeper strengths (outputs) and targets. An R value of 1 means a close relationship, 0 a random relationship.