The Feasibility of AI-based BBA

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OUTLINE

1. BBA in soft-XFEL
2. Genetic Algorithm & BBA
3. ANNs & BBA
4. Summary

BBA in soft-XFEL

The beam-based alignment is the ruler to the accelerators or FEL facilities.

The most representative BBA method (DFS):

$$m_i = \xi_i(t_i) - b_i + x_0 R_{11}(s_0, s_i) + x'_0 R_{12}(s_0, s_i) + \sum_{j}^{Nc} \theta_j R_{12}(s_j, s_i) + \sum_{j=1}^{Nq} d_j M_{ij}$$

BPM precision error
BPM misalignment

Initial beam jitter

Correctors

Quadrupole offset

Worked:
- LCLS
- European-XFEL
- PAL-XFEL

⇒ Hard-XFEL

Soft-XFEL

BBA in soft-XFEL

Taking the tilt and transverse offset of the undulator into consideration,

$$\begin{pmatrix} \Delta x \\ \Delta x' \end{pmatrix} = \begin{pmatrix} 1-Q_{11} \\ -Q_{21} \end{pmatrix} d + \begin{pmatrix} -Q_{12} \\ 1-Q_{22} \end{pmatrix} \varphi$$

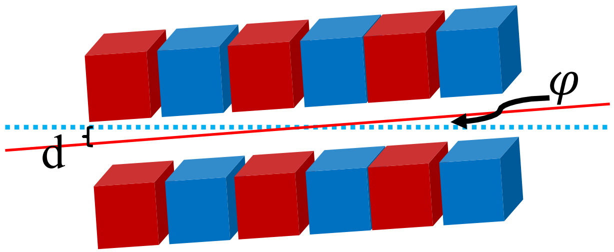

Fig1. The diagram of undulator misalignment

with Q_{ij} is the corresponding transfer matrix elements of undulator

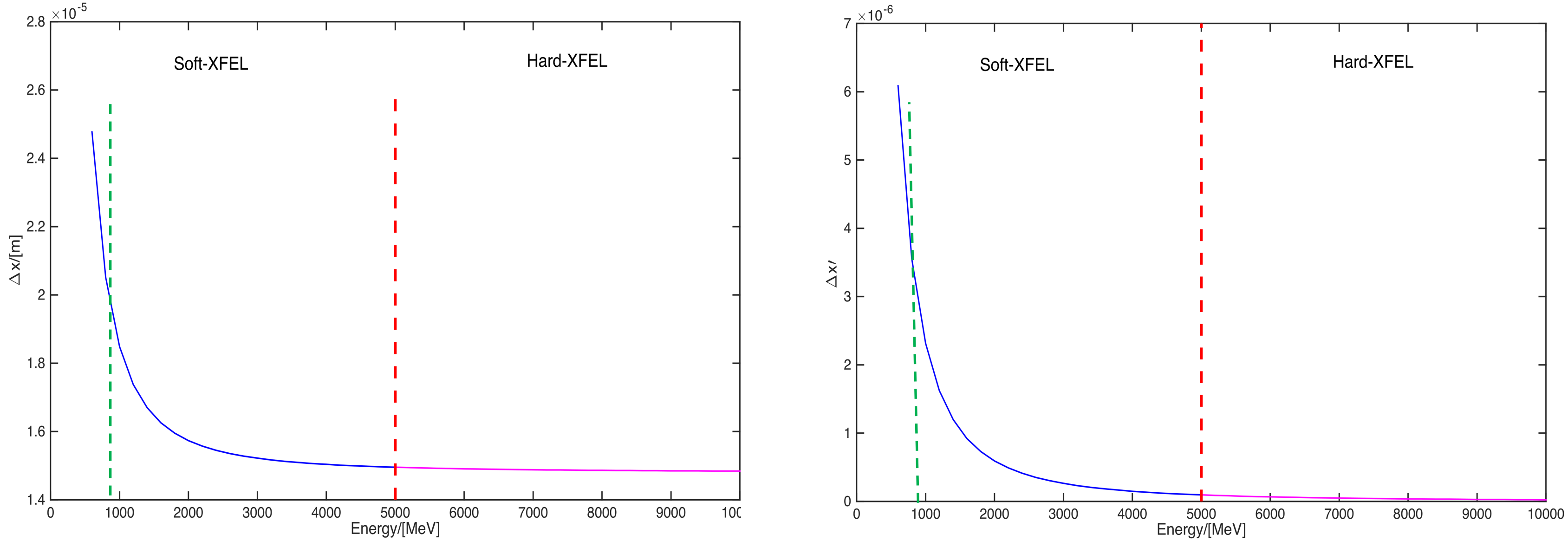

Fig2. The variation of transverse electron trajectory offset(left) and kick angle(right) caused by undulator misalignment with the electron beam energy.

OUTLINE

GA & BBA

Genetic algorithm (GA) is inspired by the process of nature selection and is commonly used to generate high-quality solutions to optimization and search problems by relying on bio-inspired operators such as mutation, crossover and selection.

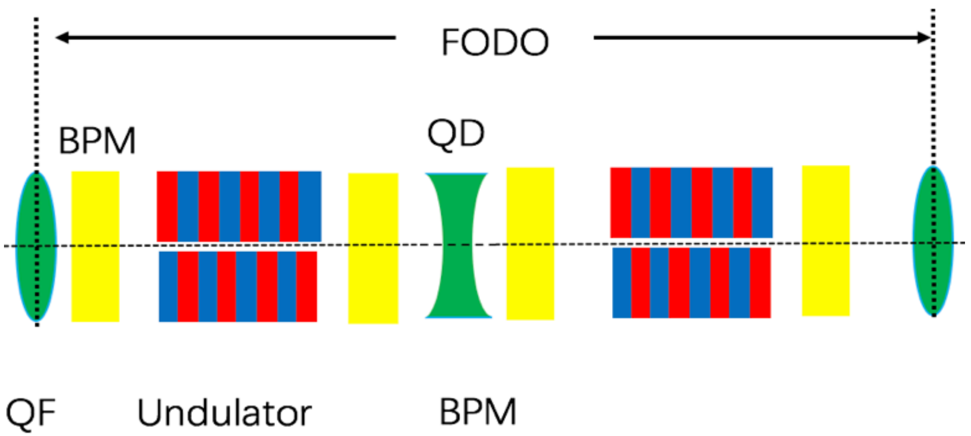

Fig1. The scheme of lattice structure

Main objective function:

$$\psi_{obj} = \sqrt{\sum_{i=1}^{12} \left| b_{1i} - b_{2i} \right|^2}$$

b_{ji}: the ith BPM reading with energy j

X: NVAR=6 ($Q_{xoff1-6}$)

Y: NVAR=18($Q_{yoff1-6}$, $U_{yoff1-6}$, $U_{ytilt1-6}$)

GA & BBA

X direction

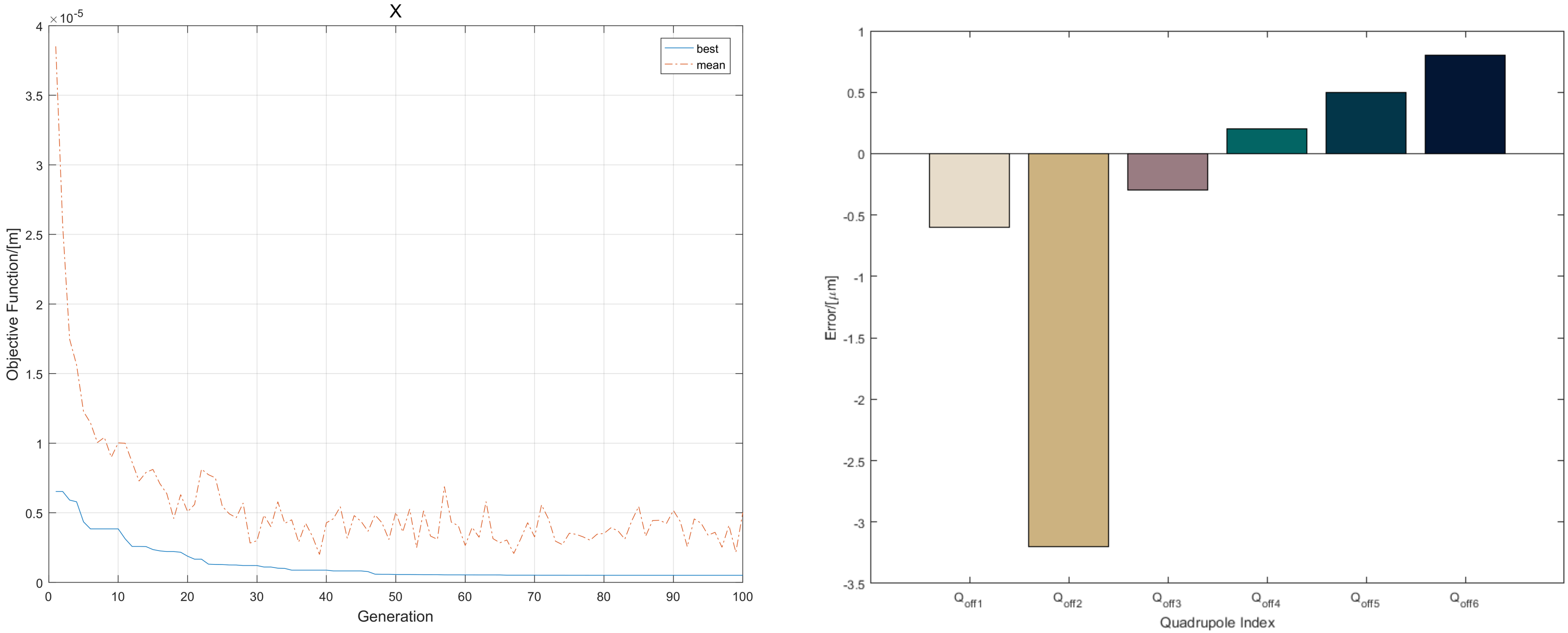

Fig1. The variation of objective function value (left) and difference between GA results and simulation settings (right). The best individual is obtained at generation 50 and the difference is about several μm

GA & BBA

Y direction

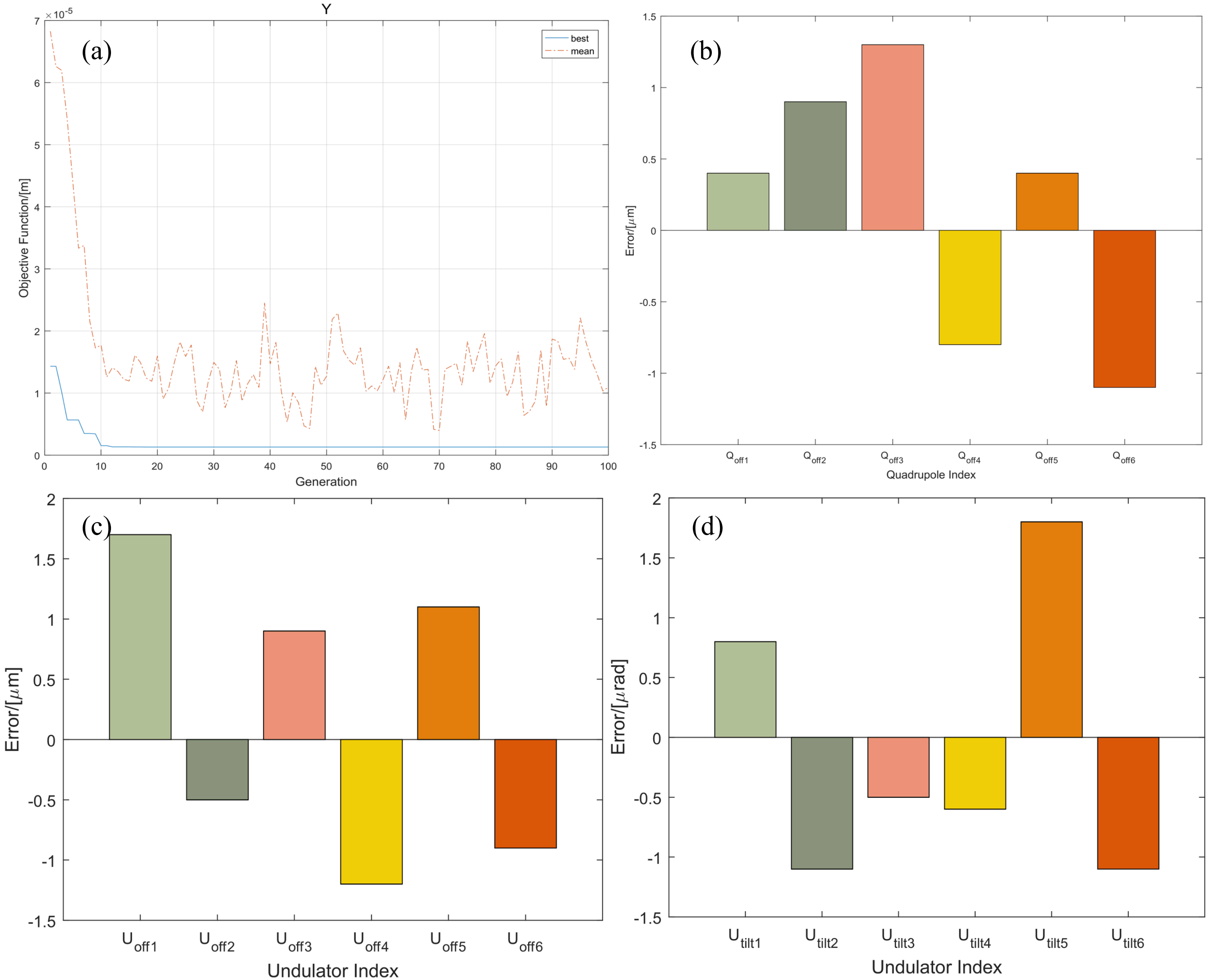

Fig1. The variation of objective function (a), the difference between GA results and simulation settings for quadrupole offsets (b), undulator offsets (c) and undulator tilts (d)

GA & BBA

Electron beam trajectory

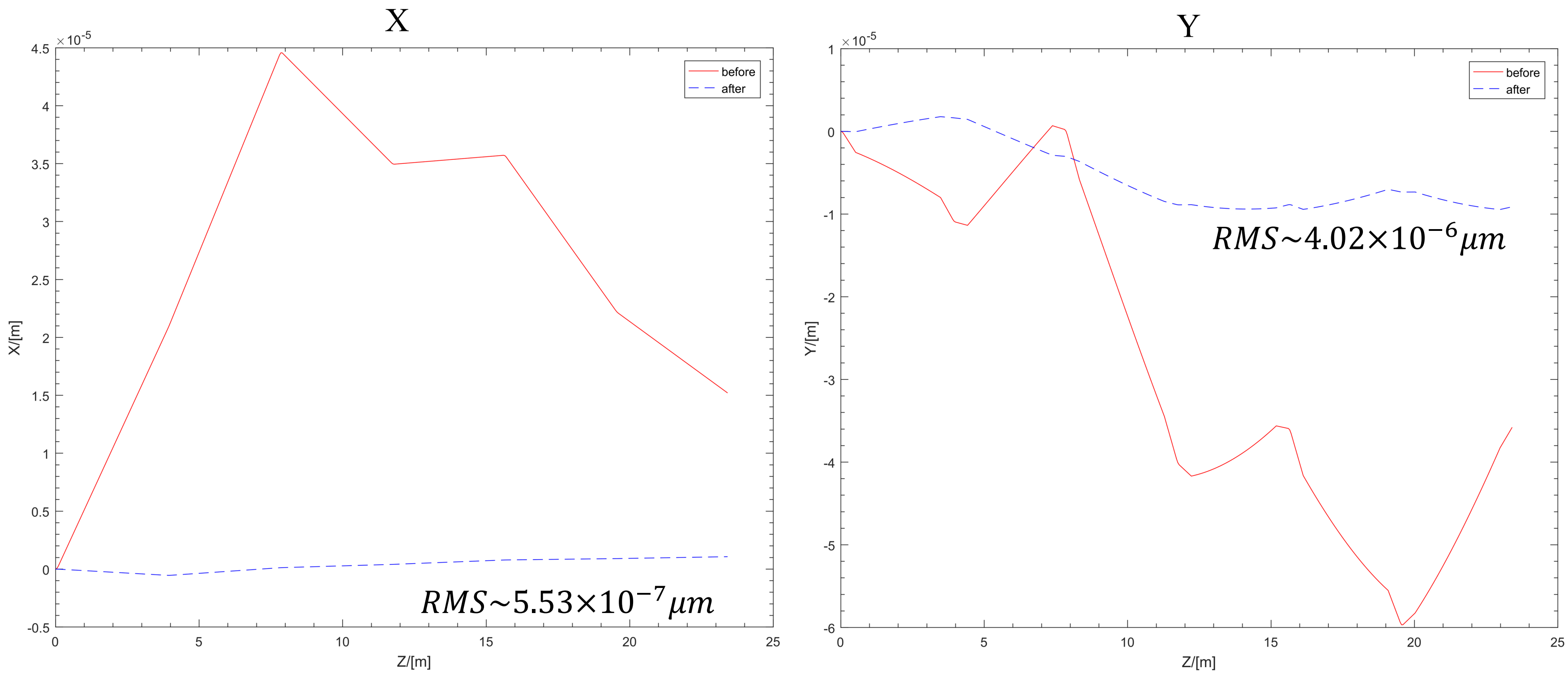

Fig1. The electron beam trajectory before and after GA in X direction (left), Y direction (right). The RMS value of orbit decline by an order of magnitude both in X and Y direction

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ANNs & BBA

ANNs have been widely used in various domains, but it's not until recently that it has been introduced in light source field.

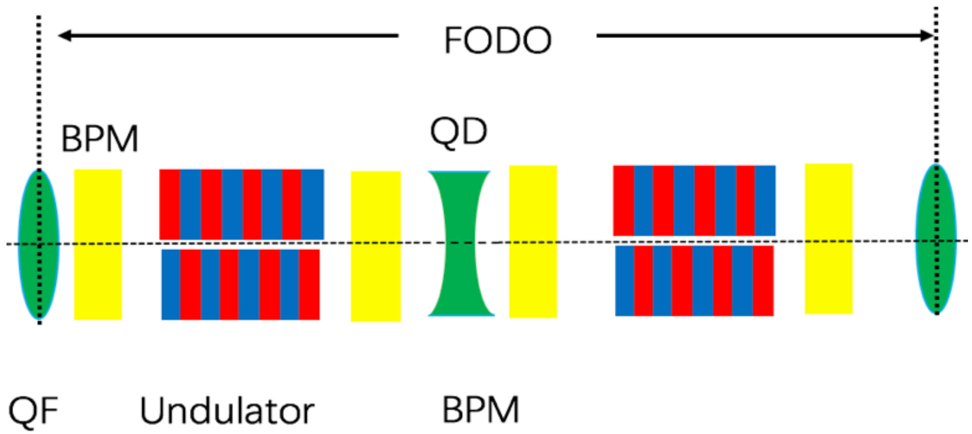


Fig1. The scheme of lattice structure

4 input: $BPM_{reading1-4}$

6 output: $Q_{xoff1,2}$, BPM_{mis1-4}

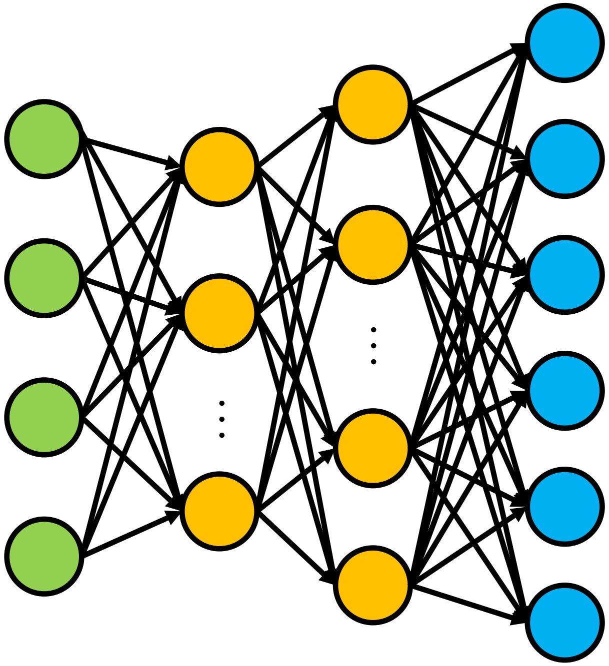


Fig2. The model network consists of four inputs(green), two hidden layers containing 15, 20 nodes(orange) and six outputs(blue). The network was trained using L-M algorithm with a dropout probability of 10%

ANNs & BBA

Training results

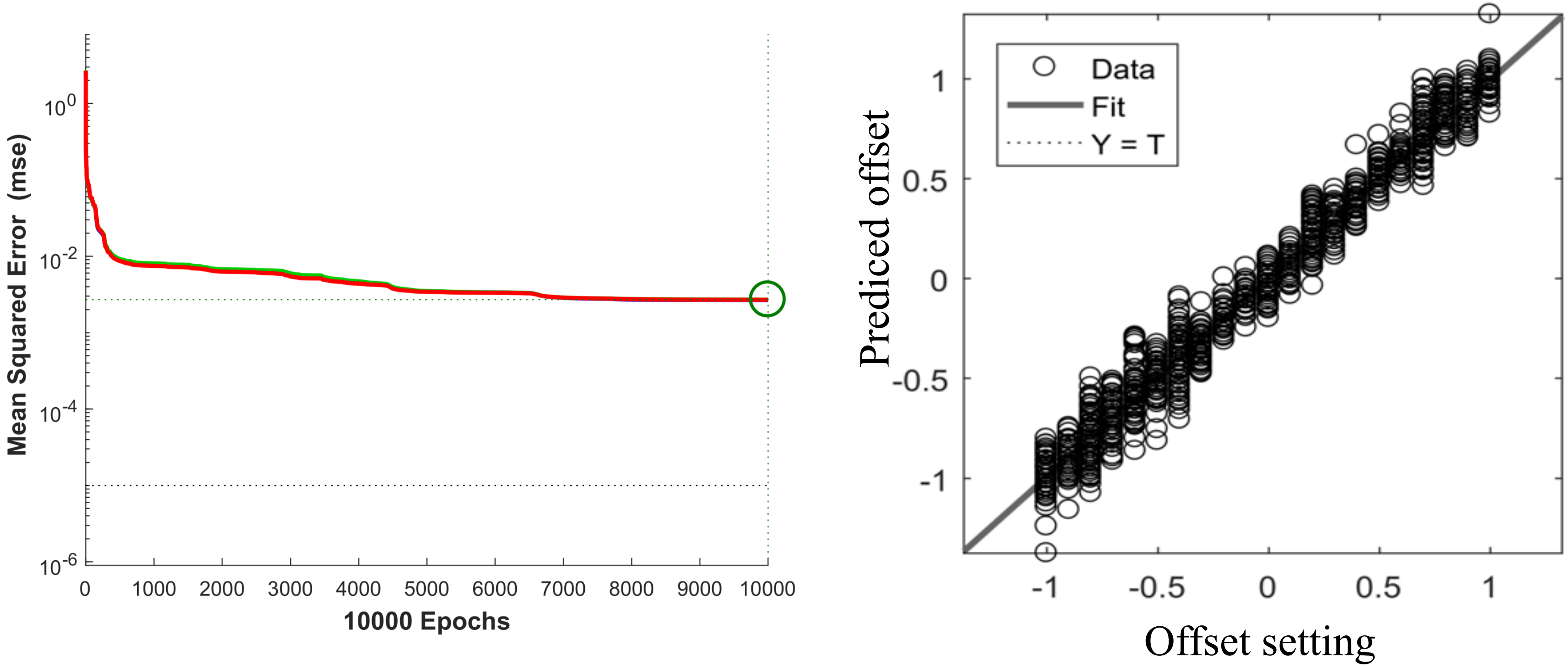
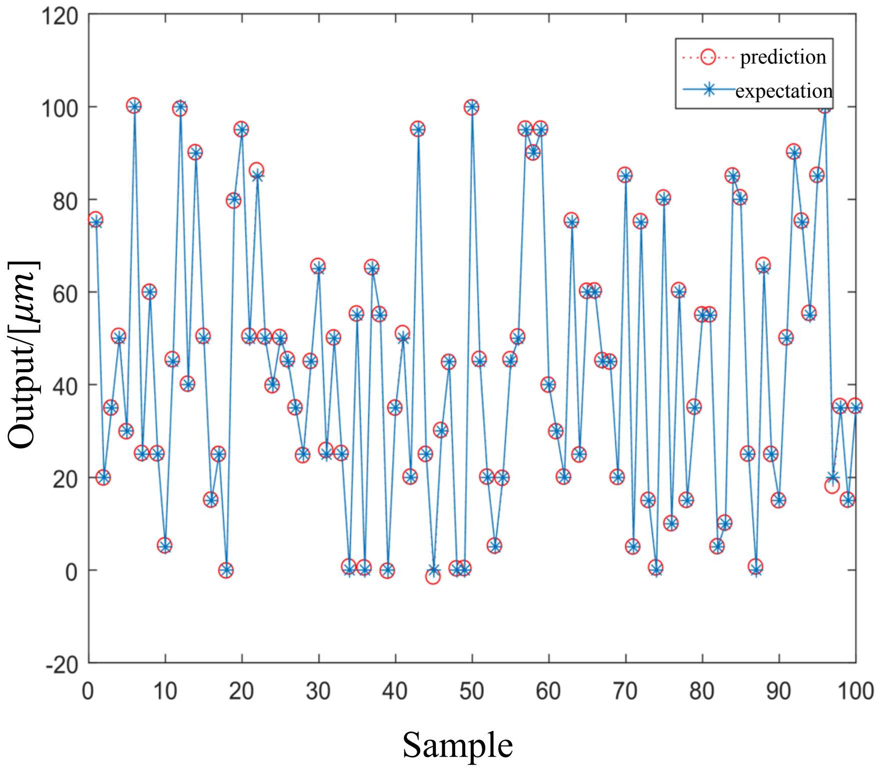


Fig1. The variation of cost function (left) and regression results (right). The best performance is 0.0027049 at epoch 10000 and the fitting equation is $y = 0.996 \times setting - 6.6 \times 10^{-5}$

ANNs & BBA

Training results



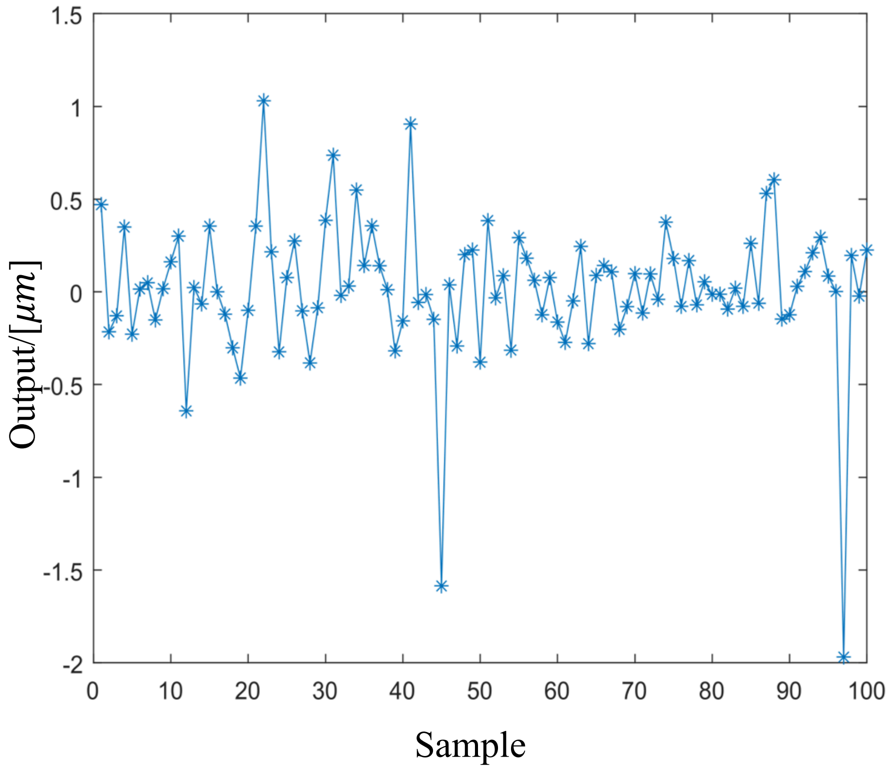


Fig1. The prediction and expectation of first quadrupole offset (left) and the predicted error (right), the samples are in test set. The error is roughly less than $\pm 0.5\mu m$

ANNs & BBA

Training results

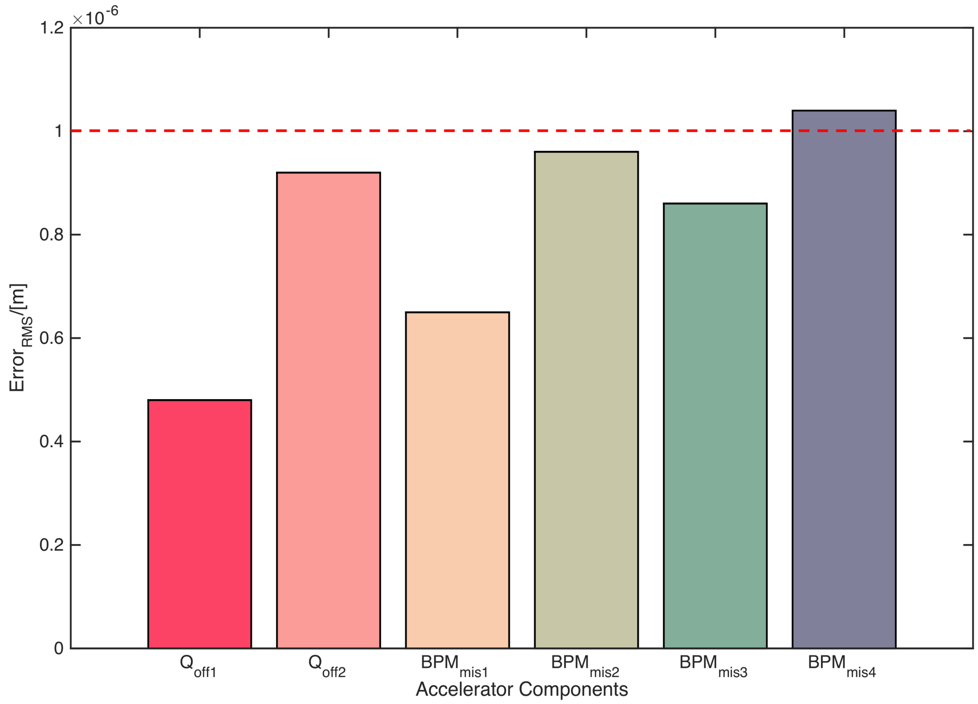


Fig1. The RMS error for different accelerator components. The result $(RMS_{error} < 1\mu m)$ indicates an acceptable accuracy.

Demerits of this method:

- A large amount of samples are needed to train the network.
- Labeled samples are difficult to acquire in experiments.
- Neuron network is sensitive to the training condition and it needs careful tuning.

Remained to be further researched…

OUTLINE

Summary

- Soft-XFEL → low electron beam energy → uncontrollable orbit disturbance caused by undulator misalignments→ difficulty in BBA

- The dilemma of BBA in soft-XFEL can be partially solved by adopting intelligent algorithms (GA， PSO…) or maybe ANNs

- There still exists many problems in these methods, and a lot of challenges and many R&Ds are underway

  Advanced GA and new better objective functions

  Way to get such labeled sample in experiment and new training method to get a more stable results

Acknowledgement

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Thank you~

Zeng Li