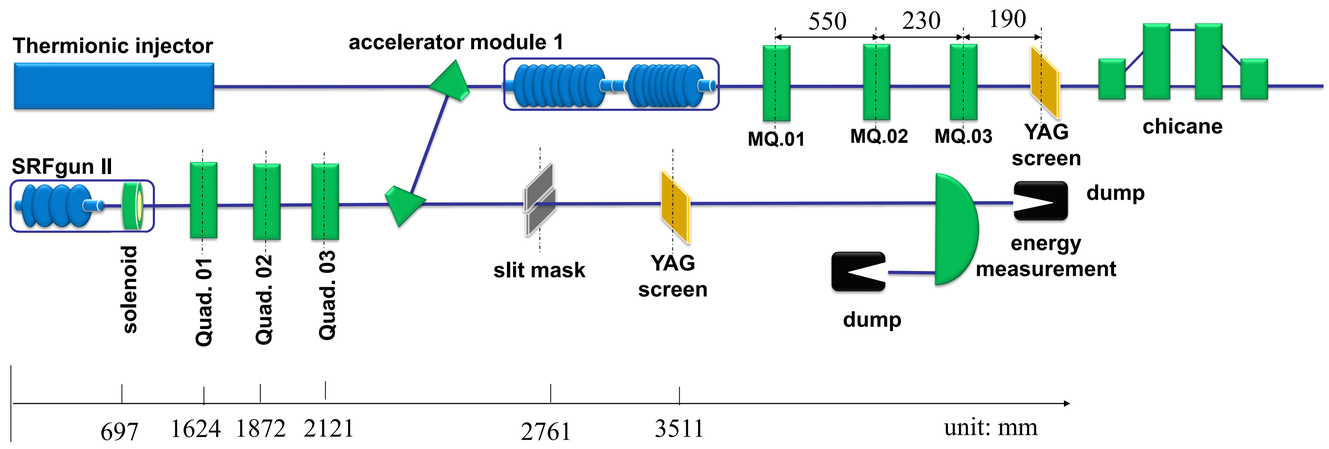
The application of deep learning on slit-scan images processing and emittance prediction

S.Ma † 1), A. Arnold 1), P.Murcek1), A .Ryzhov 1),R.Steinbrück1), J. Schaber 1,2), J.Teichert 1), R. Xiang 1)
1) Helmholtz-Zentrum Dresden-Rossendorf, Germany, 2) Technische Universität Dresden, Germany

Introduction

The radiation source ELBE (Electron Linac for beams with high Brilliance and low Emittance) delivers multiple secondary beams, both electromagnetic radiation and particles. To measure beam emittance effectively before user time, the fast and accurate methods have been developed, the continue moving slit scan for high bunch charge and the quadrupole scan for low bunch charge. In this poster the images processing based on deep learning will be presented.

Experimental layout

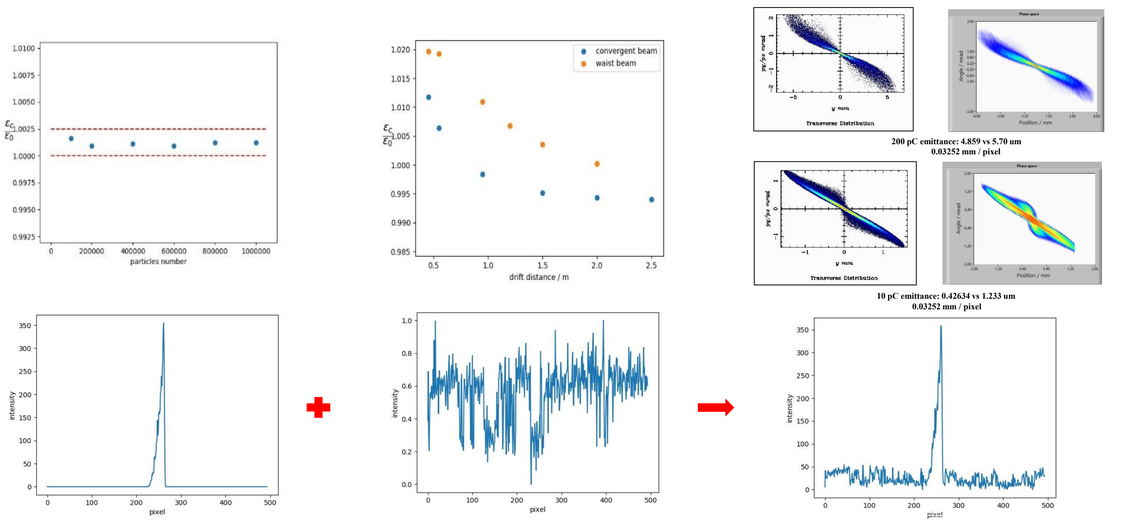


Deep learning application on silt-scan images processing

Dataset preparation based on Astra simulation

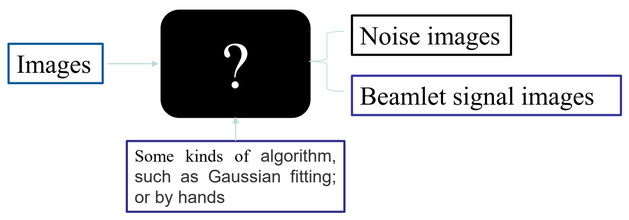
Steps:
1. Total particles number: 100,000 with somehow random parameters;
2. Cut beam into beamlet, slit width 100 um, step 10 um;
3. Every beamlet particles are used as input particles to the next drift space simulation(slit to screen);
4. Record and plot every beamlet particles position at screen position as images from camera;
5. Calculate and rebuild beam phase space at slit position ;
6. Compare calculation results with ideal results.

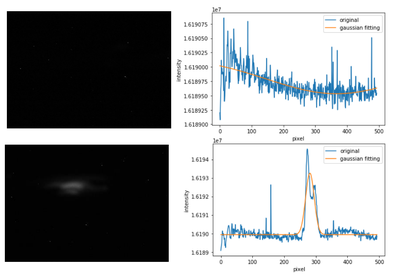
Noise data is from experiments with 100 images and random selection to add into beamlet (10% amplitude).



Simulated intensity + Real normalized noise → Simulated intensity + 10% noise

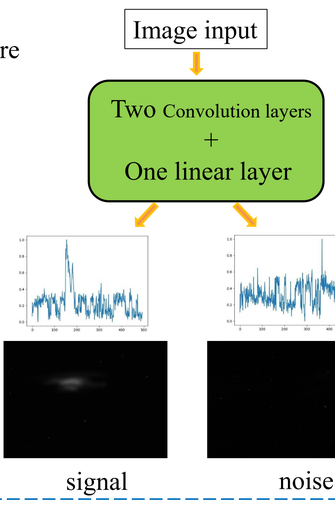
Beamlet signal VS Noise





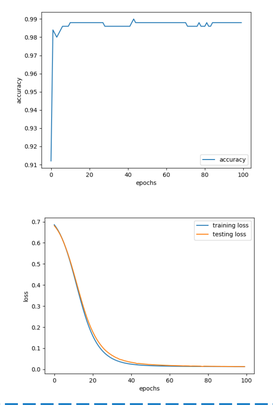
Images classification Convolutional Neural Network (CNN)

Architecture



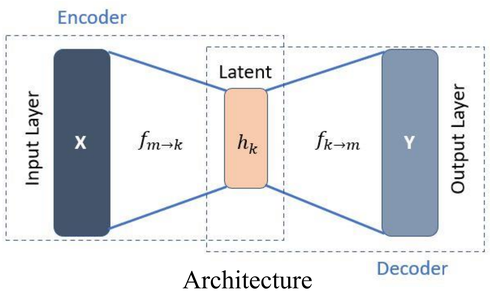
Total cases: 2500, training cases: 2000, testing cases: 500

The negative log likelihood loss: $loss(x, class) = -log\left(\frac{\exp(x_{class})}{\sum_j \exp(x_j)}\right)$



Accuracy: 98.8%

Auto-encoder filter in images data processing

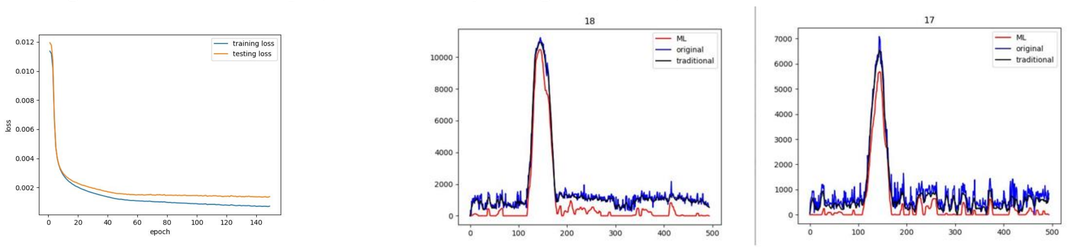


Architecture

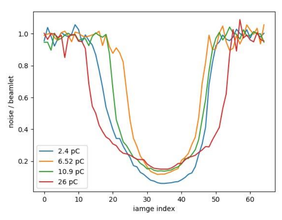
Input	Operator	c	s
494 x 1	conv1d	32	2
245 x 32	conv1d	64	2
128 x 64	conv1d	32	1
244 x 32	conv1d	1	1
484 x 1	linear	1	1

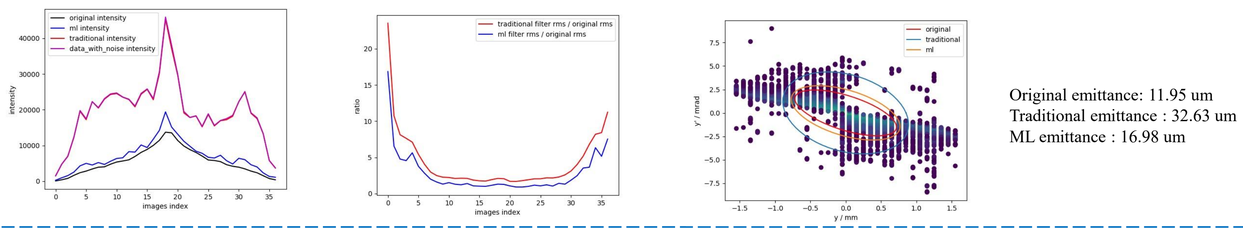
Loss function: $MSELoss = \frac{1}{N}(x - y)^2$

Total cases: 2400; 80% for training and 20% for testing. Training time ~30 minutes in PC. 100 images processing in 5 seconds. In output, if the intensity is negative values, it will be set to zero.



To test the series of images of calculating emittance, the signal-noise ratio of every image is made and will add into images as their sequence.

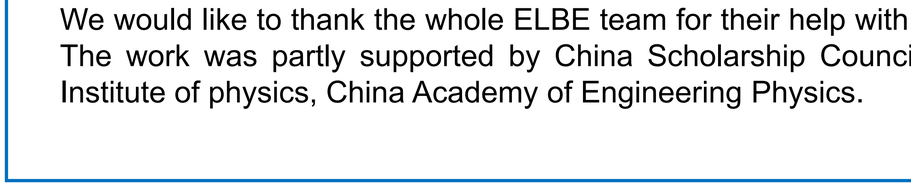




Original emittance: 11.95 um
Traditional emittance : 32.63 um
ML emittance : 16.98 um

Simulation, Experiment results and Conclusions

Beamlet signal tail cut and simulation results



Original : 6.35 um
ML filter : 5.877 um
Traditional filter : 7.021 um

Experiment results

Conclusions:

The simple image classification network has been constructed and with high accuracy, 98.8%. A ML filter based on auto-encoder has been trained and tested; Comparing with traditional filters, it is more efficient and accuracy. However, if the signal-noise ratio is too low which usually happens during the beginning and ending one or two images in every case, the rms calculation gives huge error. The solution is to cut the tail of beamlet signal.

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Contact: Shuai Ma, Institute of Radiation Physics, Radiation Source ELBE. Email: s.ma@hzdr.de