Machine Learning for Adaptive Optics

INAF ISTITUTO NAZIONALE DI ASTROFISICA
OSSERVATORIO ASTROFISICO DI ARCETRI

RSN5 2°Forum della Ricerca Sperimentale e Tecnologica in INAF

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Introduction

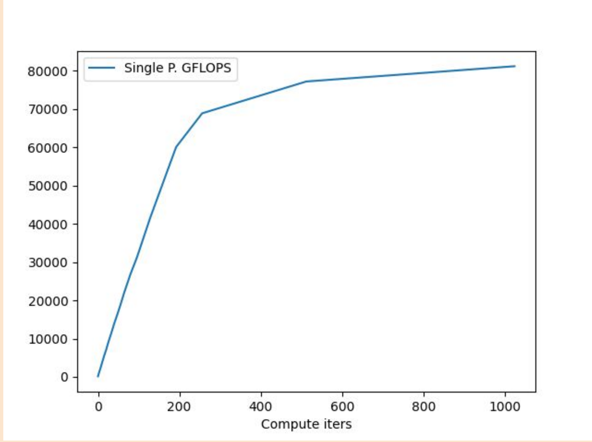
The "Machine Learning for Adaptive Optics" Data Analysis Grant 2023, part of INAF's "astrofisica fondamentale" funding, is focused on identifying machine learning techniques that can make use of telemetry data streams from existing AO systems to improve the performance and/or optimize their behavior in different atmospheric conditions, but also leveraging machine learning technique to speed up numerical simulations computation. The project is also aimed at the improvement of future AO systems. A key support to this activity is the availability of large databases of telemetry data, such as those of SOUL at LBT and ERIS at VLT, collected during the commissioning carried out by INAF researchers. During the first year of activity we were able to achieve initial encouraging results on simulated data with excellent theoretical performance. The grant was used to finance the purchase of a computing server, which is necessary to provide the needed computational power, and the participation in two international conferences, SPIE in Yokohama and ML4ASTRO2 in Catania with one talk and the publication of two papers. In this poster we briefly present the activity carried out for the grant, its current status and its goals.

Computing server

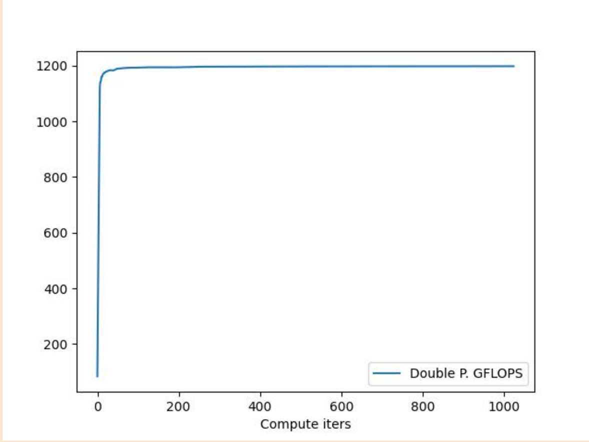
Procured and online from August 2024

AMD Epyc 48-Core 9454 2.75Ghz 256MB
384 GB DDR5-4800 ECC RAM
2 x NVIDIA L40S 48GB

- To the right: Single prec. GFLOPS scaling with vector size (up to 32*1024*1024)
- Peak around 80TFLOPS



- To the right: Double prec. GFLOPS scaling with vector size (up to 32*1024*1024)
- Peak around 1.2TFLOPS



- GPU datasheet performance:
  - Tensor = 1.466 TFLOPS
  - RT Core = 212 TFLOPS
  - Single precision = 91.6 TFLOPS
- mixbench (Phoronics opencl test suite):
  - integer = 43759 (RTX 4090 = 41836)
  - single precision = 74323 (RTX 4090 = 76251)
  - doublle precision = 1198 (RTX 4090 = 1117)

Goal of the project

The goal of the activity is to identify machine learning techniques that can use telemetry data from existing AO assisted instruments to enhance the performance of future AO systems. A key support to this activity is the availability of large databases of telemetry data such as those of SOUL at LBT and ERIS at VLT collected during the commissioning carried out by INAF researchers.

Long-term objectives (within and beyond the grant)

1. Enhanced Optical Turbulence Prediction: enhance the previous results by using more complex ML algorithms and better training over the available databases.
2. Wavefront sensing: new ways to compute the slope of the wavefront sensor.
3. Turbulence reconstruction: reconstruction from the measurements of the WFS to the residual wavefront and then to the incoming turbulence.
4. New approaches to tomography reconstruction: tomographic turbulence reconstruction done by wide field adaptive optics systems.
5. Short time scale prediction of turbulence: reduce wind driven halo in the PSF and improve vibration mitigation.
6. Optimization of temporal controllers: optimization of the temporal controlleras a function of the observing conditions.
7. PSF fitting and reconstruction: enhance the data reduction pipelines of with PSF reconstruction using ML on the databases of on-sky PSFs.

International conferences

SPIE. ASTRONOMICAL TELESCOPES+ INSTRUMENTATION

16 - 21 June 2024
Yokohama, Japan

Efficient Asterism Selection for Wide Field Adaptive Optics Systems with TIPTOP

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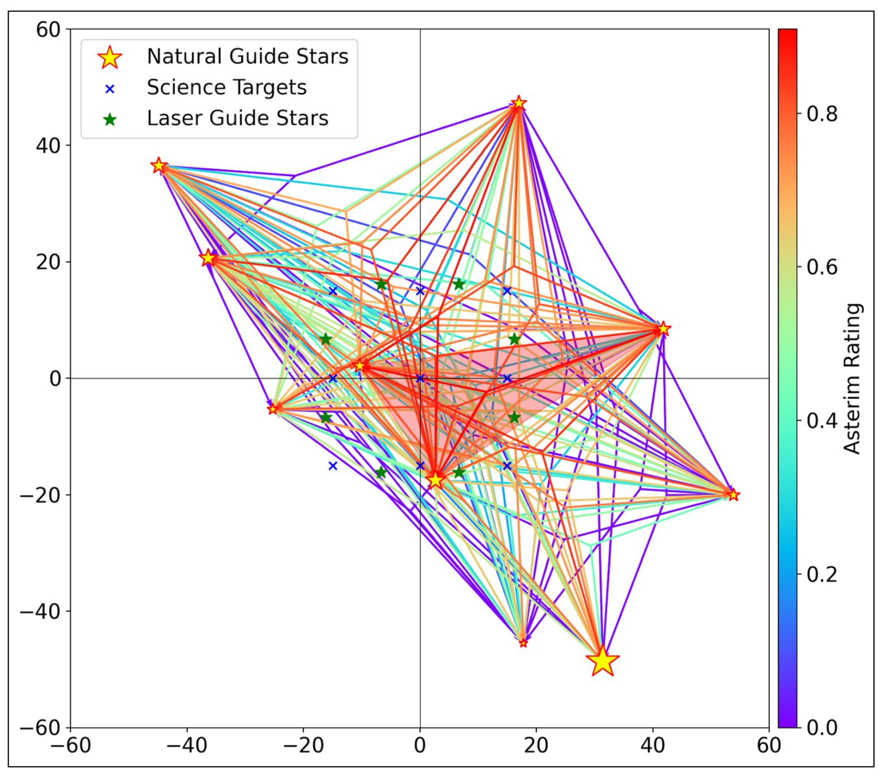
Asterism Neural Network

Since the High Order (HO) part of the simulation is fixed, we can select the best asterism based only the Tip Tilt Jitter residual σ_{TT}, which is computed by the Low Order (LO) part of the simulation (even if this requires in as input the HO part output: the PSD of the high order modes residuals).

Our approach quickly evaluate asterisms is the following:

1. Using TIPTOP, we compute a large number of simulations (thousands) for the specific case, with randomly generated asterisms (varying positions and magnitudes of the NGSs) and we then evaluate σ^A_{TT}.



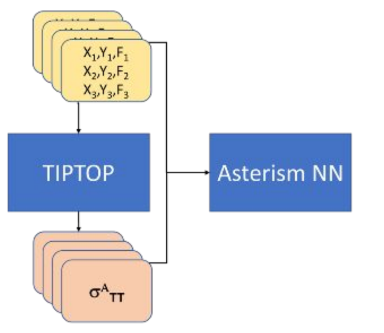


Fig. 2 Neural Network Training.

2. Train a Neural Network model to perform the regression from the input asterism features (9 scalar values: X, Y coordinates and Flux on the NGS sensors, for each of the 3 stars) to the associated output σ^N_{TT}.
   1. Asses the NN uncertainty in prediction U_N:

$$E_\sigma = (\sigma^A_{TT} - \sigma^N_{TT}) / \sigma^A_{TT}$$

$$U_N = 1.6 * \mathbf{RMS}(E_\sigma)$$

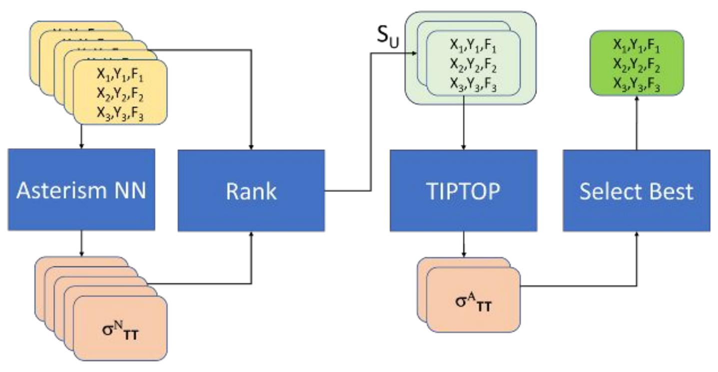


Fig. 3 Overall Asterism Selection process.

3. Use the NN model to evaluate a specific case:
   1. Rank all of the possible asterisms based on σ^N_{TT}
   2. Define the set of asterisms S_U for which: $\sigma^N_{TT} < \min(\sigma^N_{TT}) \times (1+U_N)$ **[+the 3 best ranking ones]***
   3. Compute σ^A_{TT} for the asterisms in S_U using TIPTOP, select the one yielding $\min(\sigma^A_{TT})$

A machine learning approach to AO parameters estimation on the wavefront sensor

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[1]INAF - Osservatorio Astrofisico di Arcetri,

Our goal is to provide an accurate technique to estimate optical and atmospheric parameters from Adaptive Optics System telemetry data. We focus on the following quantities:

- **Strehl Ratio**
- **Seeing**
- **Wind Speed (per layer)**
- **External Scale (L0)**

We use the GRU Neural Network provided by ***pytorch*** library, combined in sequence with a MLP (Multi Layer Perceptron) one of such networks is trained for each estimated quantity.

GRU = Gated recurrent unit
MAPE = Mean Absolute Percentage Error

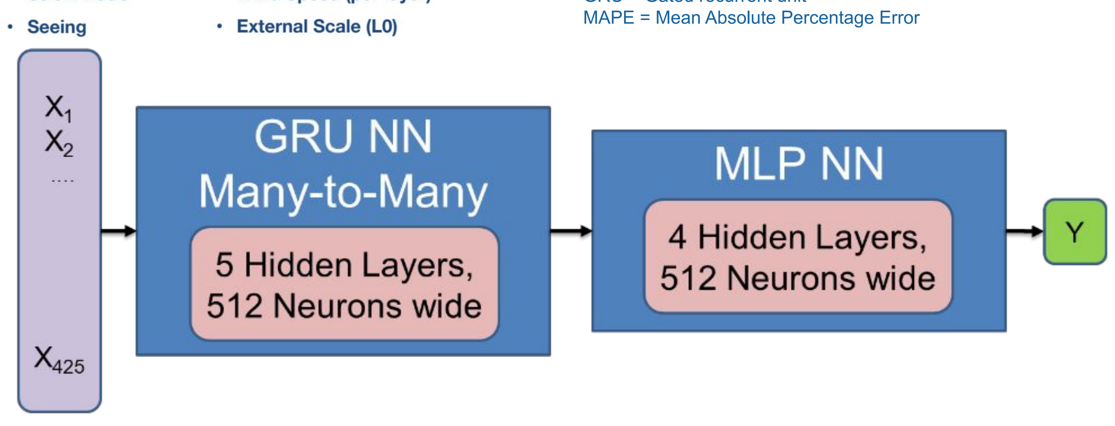

Fig. 2 – Our Neural Network structure.

Quantity	Analytical - from references (SH WFS)	Analytical - Our Implementation (PWFS)	Our Method - Test Set (PWFS)
Strehl Ratio	7.3%+2.6% Bias[6]	31.84%	5.72%
Seeing	>22%[7], 6.4%[6]	12.91%	2.29%
Wind Speed (Layer 0)	N.A.	23,81% ~[6]	12.2%
External Scale (L0)	N.A.	N.A.	3.32%

Table 1 – MAPE Errors to summarize methods results.

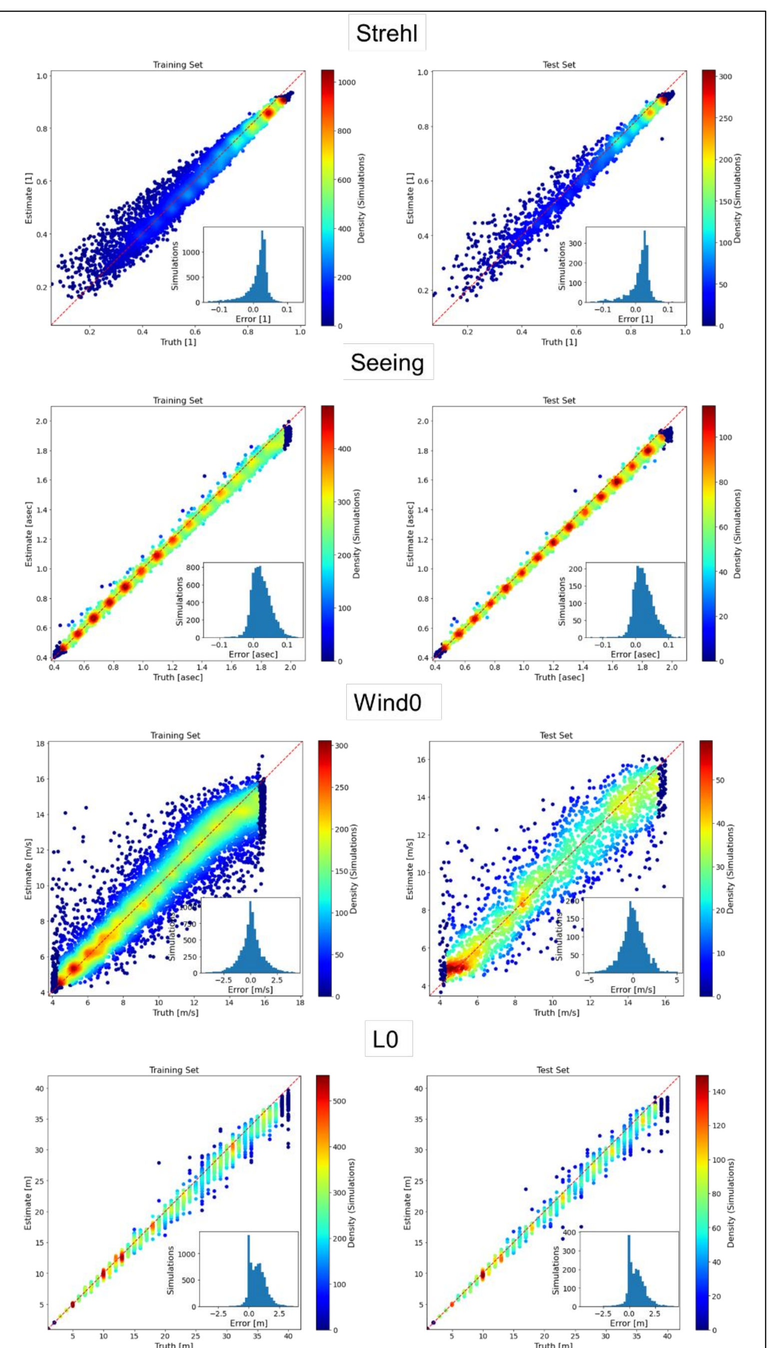

Fig. 3 – Distributions and scatter plots of the errors.

MACHINE LEARNING FOR ASTROPHYSICS 2ND EDITION CATANIA, 8-12 JULY, 2024

Recurrent Neural Networks for Adaptive Optics parameters estimation

11 Jul 2024, 10:20
20m
Conference Room (Catania)
Oral Presentation
Miscellaneous

Speaker
Fabio Rossi (INAF)

Conclusion

The first year of the grant proceeded as expected, and demonstrated that machine learning techniques can be effectively applied to adaptive optics problems. The initial results look promising, and with the new computational server that has recently come on line, we will be able to speed up our analysis. We are now planning to take further steps towards implementing our neural networks in a real system, as well as focusing the work on some of the other objectives.

Public repositories github.com/FabioRossiArcetri/ml4ao github.com/astro-tiptop/TIPTOP