Shallow Recurrent Decoder for Aero-Optical Wavefront Sensing and Forecasting

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Abstract

SHRED is a SHallow REcurrent Decoder neural network. In aero-optics, where beam transmission meets turbulent aerodynamic flow, SHRED, provided the time histories of *sparsely placed sensors*, can *reconstruct* and *forecast* aero-optical wavefronts.

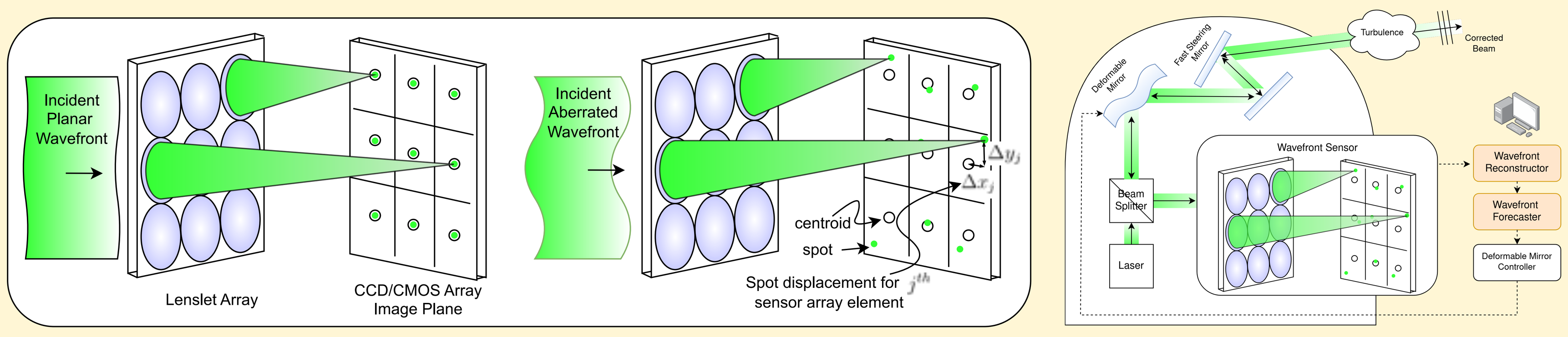
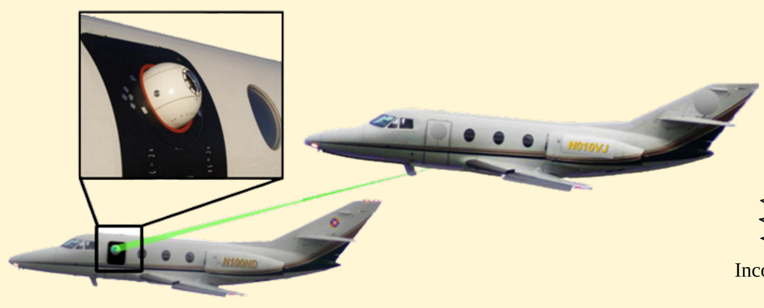


Figure 2. (left) Schematic of a Shack-Hartmann wavefront sensor, which are used in the AAOL-T and reconstruct incident wavefronts from "local tilts" generated by beamlet spot displacements onto a sensor array. (right) SHRED is a candidate predictive controller for an adaptive-optics loop, which requirs low latency forecasts to correct beam aberrations via a deformable mirror.

Aero-Optics with In-flight Data

In airborne optical environments, aero-optical effects such as turbulent boundary layers cause rapid index of refraction fluctuations that induce aberrations in transmitted wavefronts. The fast-scale physics in the turbulent flows lead to an extremely low latency requirement for control. Computationally efficient forecasting is critical in free space optical systems [1]. Thus we propose SHRED [2], given its ability to rapidly forecast turbulent flow fields for short-term predictive control.



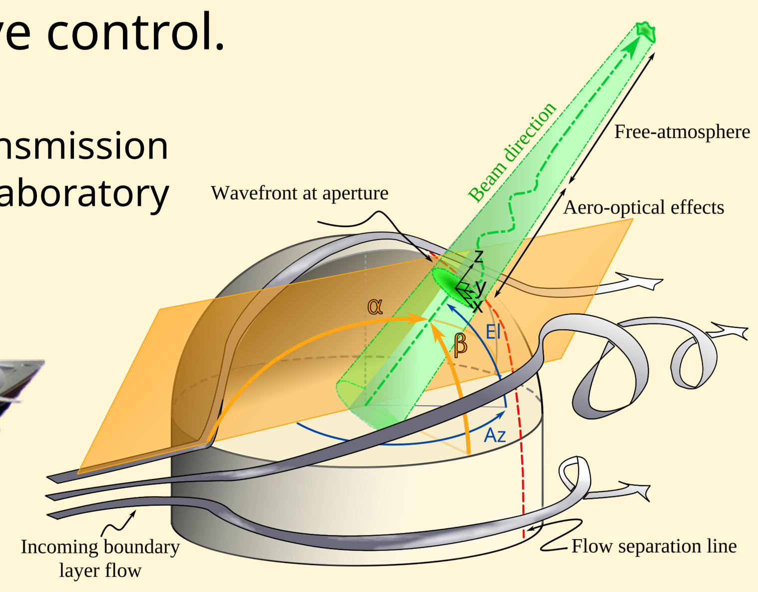


Figure 1. We study in-flight wavefront transmission data from the Airborne Aero-Optics Laboratory Transonic or AAOL-T [3].

SHRED for Wavefront Reconstruction and Forecasting via Sparse Sensor Placements

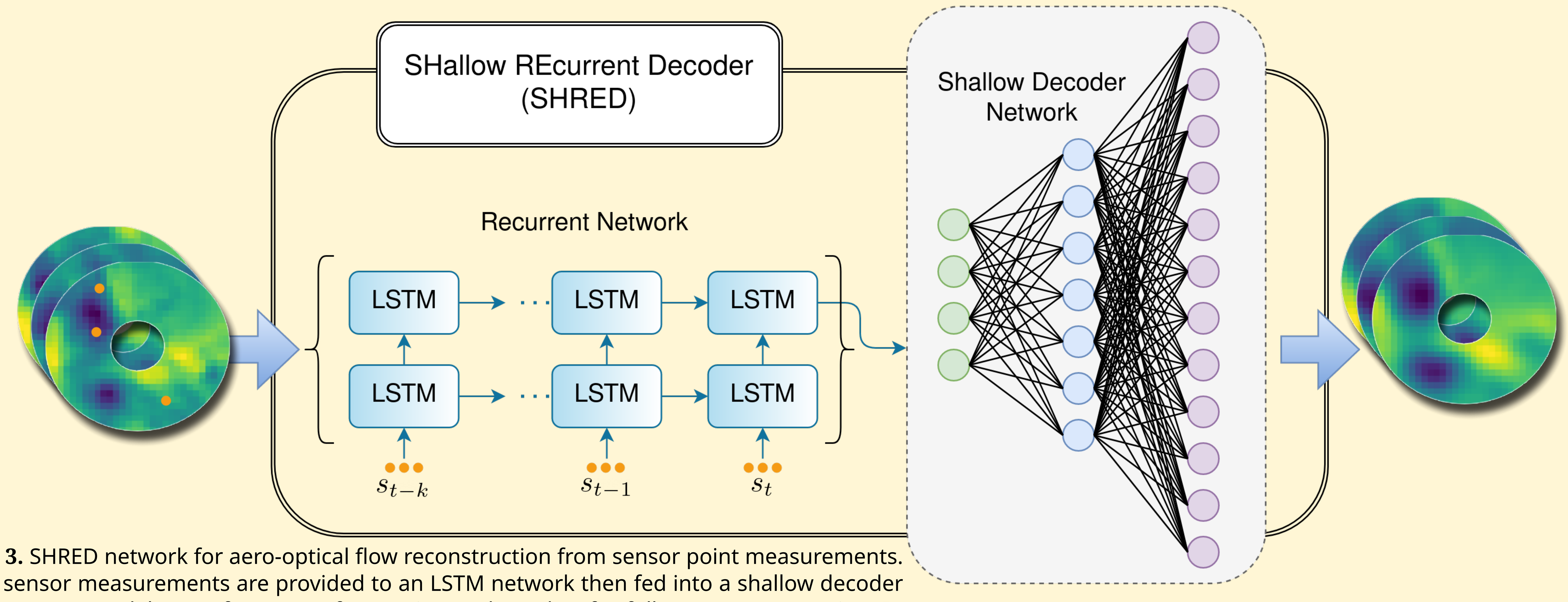


Figure 3. SHRED network for aero-optical flow reconstruction from sensor point measurements. Sparse sensor measurements are provided to an LSTM network then fed into a shallow decoder to devleop two models: one for sensor forecasting and another for full state reconstruction. In tandem, we achieve high-fidelity forecasting suitable for adaptive optics in turbulent scenarios.

Results & Outlook

Sub-millisecond aero-optical wavefront forecasting in highly turbulent conditions is possible with SHRED. Aero-optical aberrations are sensitive to beam direction and airborne optical platform geometry and elevation, yet SHRED provides a lightweight framework for quick reconfiguration to serve as a low latency predictor for adaptive optics control. Additionally, due to SHRED's sparse sensor placement requirement, there is inherent possibility for data compression when recording and reconstructing high-fidelity wavefronts.

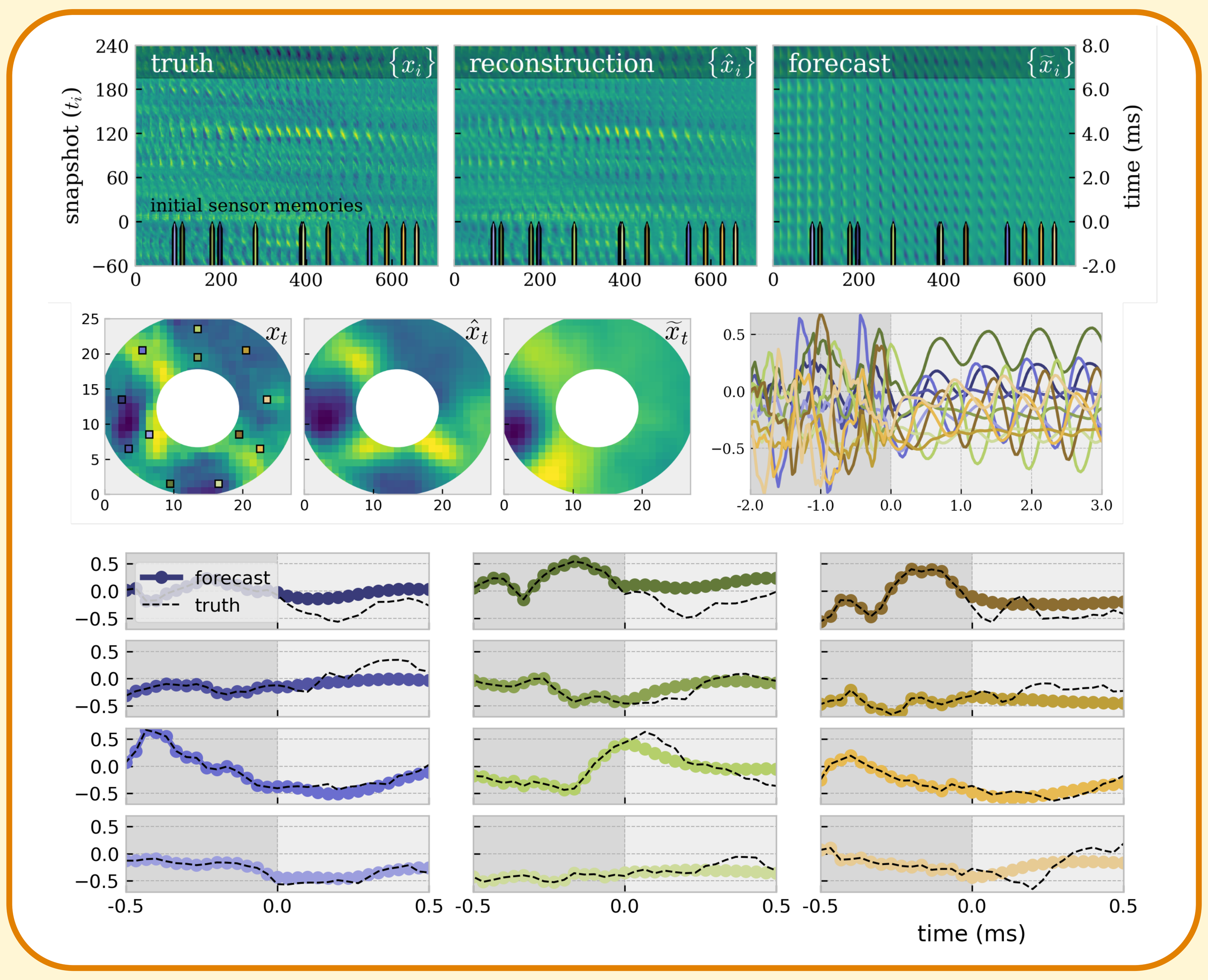


Figure 4. Truth, reconstruction, and forecasted snapshots from SHRED on a AAOL-T test set. The inputs are 12 radially dispersered sensor recordings, each with a 60 snapshot memory (~2 ms). Reshaped wavefront examples at t=200 are shown. The forecasted time series for the 12 sensors are shown together and again separately for a shorter, relevant timeframe for adaptive optics.

References

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