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Tensor-based predictive control for large-scale AO

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Summary

We propose a data-driven predictive control algorithm for large-scale single conjugate adaptive optics systems. At each time sample, the Shack-Hartmann wavefront sensor signal sampled on a spatial grid of size $N \times N$ is reshuffled into a d-dimensional tensor. Its spatial-temporal dynamics are modeled with a d-dimensional autoregressive model of temporal order p where each tensor storing past data undergoes a multilinear transformation by factor matrices of small sizes. Equivalently, the vector form of this autoregressive model features coefficient matrices parametrized with a sum of Kronecker products between d factor matrices. We propose an Alternating Least Squares algorithm for identifying the factor matrices from open-loop sensor data. When modeling each coefficient matrix with a sum of r terms, the computational complexity for updating the sensor prediction online reduces from $\mathcal{O}(pN^4)$ in the unstructured matrix case to $\mathcal{O}(prdN^{\frac{2(d+1)}{d}})$. Most importantly, this model structure breaks away from assuming any prior spatial-temporal coupling as it is discovered from data.

The algorithm is validated on a laboratory testbed that demonstrates the ability to decompose accurately the coefficient matrices of large-scale autoregressive models with a tensor-based representation, hence achieving high data compression rates and reducing the temporal error especially for large Greenwood per sample frequency ratio.

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