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(Semi-)analytical and non-linear approaches towards optical gain compensation for pyramid sensors

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Summary

The pyramid wavefront sensor relates the incoming wavefront and the corresponding sensor signal in a non-linear way. If the sensor is operated around a non-zero setpoint, a non-linearity induced sensitivity loss, known as optical gain effect, can result in over- or under-applied corrections when using linear wavefront reconstructors. The optical gain effect varies especially with the modulation amplitude of the sensor, the statistics of the sensed phase and spatial frequencies contained in a given mode. We describe several concepts to take into account the non-linearity effects of the pyramid sensor in order to obtain an improved reconstruction quality.

One possibility is to measure or (semi-)analytically compute a non-linearity factor. The common idea of these approaches is to retrieve the non-linearity of the pyramid sensor and apply necessary adaptions as a variable (frequency dependent) gain in the reconstruction process. This can be performed, e.g., by registration of the measurements, by analyzing the response to fed frequencies in numerical simulations or by calculating the parameter analytically. Miscellaneous optical gain compensation methods using non-linearity measurements have already been introduced in order to enhance the reconstruction quality.
The analytical approach consists in a linearization of the non-linear pyramid sensor model around a non-zero phase followed by an application of already existing model-based linear reconstructors. Here, we are particularly interested in the adaption of the P-CuReD algorithm.

As an alternative, we investigate non-linear wavefront estimation for which we introduce two new methods called LIPS (Landweber Iteration for Pyramid Sensors) and KLIPS (Kaczmarz-Landweber Iteration for Pyramid Sensors). Especially for the non-modulated sensor, we attain accurate wavefront reconstruction by still keeping the numerical effort feasible for large-scale AO systems.

Additionally, in the context of linear wavefront estimation using pyramid sensors, we present the core ideas of a new wavefront reconstruction method based on an augmented steepest descent approach that takes the reconstructed wavefronts of previous steps in an AO loop into account. For this attempt, we experience a faster convergence to high Strehl ratios in closed loop applications.

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