Time-Resolved Pyramid Wavefront Sensing using Photon-to-Digital Converters

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Abstract

The University of Sherbrooke and the National Research Council Canada are developing novel photon-to-digital converters (PDCs) based on single photon avalanche diodes (SPADs). A PDC is a single-photon detector array coupled to application-specific digital electronics to process information such as the time of arrival of each photon using embedded time-to-digital converters (TDCs). This technology enables very accurate time stamping (sub-50 pico-second FWHM precision), and does not require advanced cooling systems, which makes it potentially quite affordable. In addition, the on-chip digital processing can be tailored to the given application, in this case, adaptive optics.
Our idea is to use a PDC as detector for a pyramid WFS (PWFS). This will allow recording the time of arrival of each photon during the PWFS modulation cycle and then reconstructing frames corresponding to different time slices in this cycle. Some of these frames, corresponding to when the spot crosses an edge of the pyramid, contain a lot of signal, while others, corresponding to when the spot is mostly on a face of the pyramid, contain little signal and mostly noise. By rejecting the latter frames in the wavefront reconstruction process, we are able to increase the signal-to-noise ratio of the measurement and therefore the sensitivity of the sensor. We have called this frame selection process within the modulation cycle of the PWFS "time-resolved wavefront sensing" (TRWFS).
We have simulated TRWFS for a PWFS AO system on an 8-meter telescope with pupil images of 60 pixels in diameter. This is similar to the GPI 2.0 configuration. Our preliminary results show that applying the TRWFS process in the reconstruction of the first 36 KL modes provides significant improvement in delivered image quality on faint natural guide stars, consistent with an increase in sensitivity of the WFS. Higher order modes do not benefit from the frame selection process and therefore can be reconstructed using the entire set of frames stacked together, as in a classical system.

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