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TESTS OF NOVEL WAVEFRONT RECONSTRUCTORS ON SKY WITH CANARY

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Abstract. We have tested two novel wavefront reconstruction algorithms, CuReD and HWR, using CANARY. We performed tests using telescope simulator and "on sky", using William Herschel Telescope. Both CuReD and HWR ran successfully in closed loop. We compared their performance with the performance of the traditional wavefront reconstruction (MVM) by measuring the Strehl ratio. The Strehl ratio obtained with CuReD is at least as high as the one of MVM.

1 Introduction

The conventional least square and minimum variance approach for wavefront reconstruction (multiplying the gradient vector with the command matrix, MVM) will be too slow for the E-ELT instrument EPICS, using currently available or proposed computational hardware. Therefore alternative algorithms have been developed with the aim to reconstruct the wavefront faster than MVM and ideally with a similar quality. For this paper we investigated the performance of two such algorithms, CuReD and HWR, on the William Herschel Telescope with CANARY.

2 CuReD and HWR algorithms

The underlying principle of CuReD [1] and HWR [2] is to obtain the wavefront values by summing up the measured gradients. There are several different ways of doing this. CuReD sums up gradients along horizontal and vertical lines (left plot of Figure 1), whereas HWR sums them up along diagonal lines (right plot of Figure 1). Each of the two approaches has some disadvantages that are addressed in different ways, which affects the properties of the result. Therefore the quality of the reconstructed wavefront needs to be tested and verified in practice.

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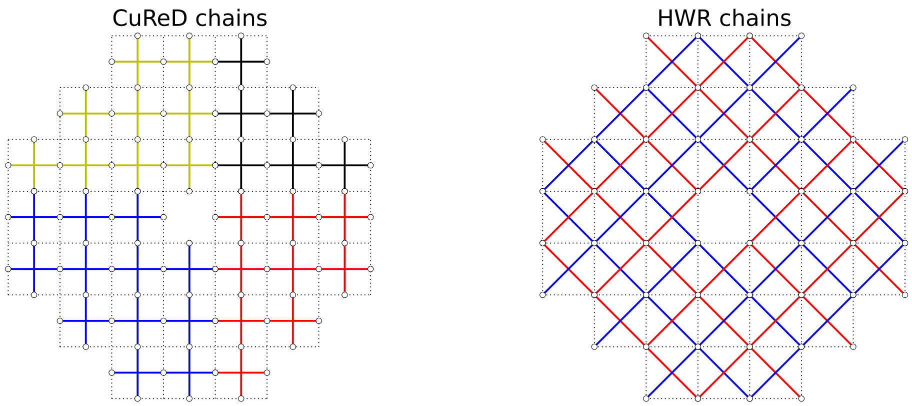

Fig. 1. Left: Lines along which CuReD sums up gradients. Four different colours represent four domains. (See [1] for more details.) **Right:** Lines along which HWR sums up gradients. Two different colours represent the two groups of lines that are not connected through common subaperture corners. (See [2] for more details.)

3 Experimental setup

3.1 CANARY

CANARY [3,4] is an instrument that was developed to test on sky the Multi-Object adaptive optics technique. For our tests it was run in the "Single-Conjugate AO" mode with a closed loop. For this mode it has a single closed-loop wavefront sensor with 7x7 subapertures; 36 of them are illuminated and used to measure wavefront gradients. The deformable mirror (DM) has 52 actuators in an 8x8 array. The actuator voltages were updated with a frequency of 150 Hz.

CANARY uses the Durham AO Real-time Controller (DARC) [5,6] for real-time control. This system has a modular design with dynamic loading of libraries, which makes it possible to easily switch between different wavefront reconstruction algorithms within fractions of a second, even while the AO loop is closed. DARC is written in C, runs on Linux and it is straightforward to add modules. Additionall, DARC can be linked with the Durham AO Simulation Platform (DASP) [7–9], which allows extensive testing of real-time algorithms to be performed and was very helpful for finding errors within the real-time implementation of the HWR algorithm.

The measurements presented in this paper were taken with CANARY on the William Herschel Telescope at Observatorio del Roque de los Muchachos, La Palma, Canary Islands. The diameter of the telescope's primary mirror is 4.2 m.

3.2 Mapping matrix

Both CuReD and HWR produce the wavefront values at subaperture corners. In the perfect Fried geometry the subaperture corners would perfectly coincide with the positions of the DM actuators. However, in the reality the DM and the Shack-Hartman lenslet array are slightly displaced. To account for that we construct a "mapping matrix" and obtain the actuator commands as a dot product of the mapping matrix and the CuReD (or HWR) output.

We constructed the mapping matrix from the poke matrix in the following way. Each line of the poke matrix contains the gradients recorded after poking the corresponding actuator. We provide these gradients as the input to CuReD (or HWR), one line of the poke matrix at a time, and save the output in the corresponding line of another matrix. After all the lines of the poke matrix have been processed, we calculate the pseudo-inverse of the resulting matrix and transpose it to obtain the mapping matrix. For HWR an additional step was performed before inverting and transposing: the matrix values were replaced by numerically fitted values using a model, and off-diagonal blocks of elements were set to zero so that the inverted matrix retained the same sparsity.

4 Results

For a large system CuReD will be 2-3 orders of magnitude faster than MVM [1]. However, since the CANARY deformable mirror only has 52 actuators, which is three orders of magnitude smaller than the proposed EPICS DM, the speed of the wavefront reconstruction was not studied at all. We only studied the quality of the reconstructed wavefront by measuring the Strehl ratio.

4.1 Measurements using telescope simulator

We first tested the quality of wavefront reconstruction using the telescope simulator, which uses rotating phase-screens to simulate the effects of the atmosphere. Both new algorithms ran successfully in closed loop. The results are summarised in Table 1. CuReD performed slightly better than the traditional MVM whereas HWR was slightly worse.

Table 1. Average Strehl ratios obtained with the telescope simulator.

Reconstructor	average Strehl ratio
MVM	0.220
CuReD	0.232
HWR	0.214

4.2 Measurement on sky

We performed on-sky measurements in the night of October 26th-27th 2012 in two different time slots. In each time slot a different star was used, both were of magnitude about 11. The atmosphere conditions were very good ($r_0 \sim$ 20-30 cm) and stable. The data for Measurement 1 were taken between 21:34 and 22:14 and are shown on the left plot of Figure 2. The data for Measurement 2 were taken between 1:12 and 2:02 and are shown on the right plot of Figure 2. The exposure time for each data point was about 1 minute.

4.2.1 Measurement 1

There are no r_0 data available for Measurement 1. There is no trend apparent in the left plot of Figure 2 so we assume the atmosphere conditions have not changed during the measurement and we fit the points for each reconstructor with a constant (horizontal lines). MVM and CuReD performances are similar whereas HWR is slightly worse. After the first 12 data points we changed the gain (parameter of the closed loop) from 0.3 to 0.5. No change in performance is observed.

4.2.2 Measurement 2

During Measurement 2 we also recorded r_0. From the right plot of Figure 2 one can see that generally higher values of Strehl Ratio correspond to higher values of r_0. The fitted lines show that CuReD performs similarly as MVM, whereas HWR is slightly lower.

4.3 Discussion

CuReD seems to reconstruct the wavefront with a similar quality than MVM, or even slightly better. HWR seems to be slightly worse.

While performing these measurements we observed an unexpected shape in the plot of actuator voltages for HWR, which might have impacted its the performance. Later we found out that this was due to a problem in the construction of the mapping matrix. This is now fixed but we have not yet been able to repeat the measurements to see how this affects the performance.

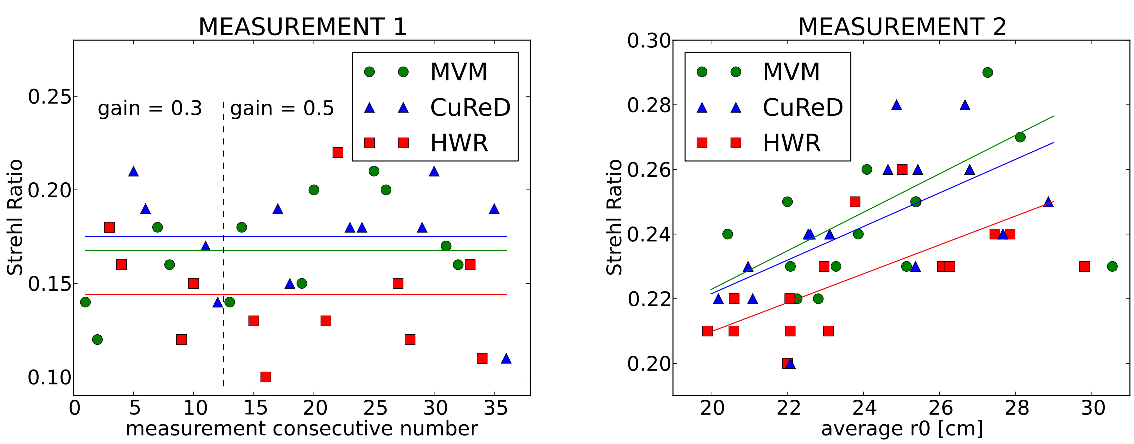

Fig. 2. Left: The Strehl ratio measurements for Measurement 1, plotted against the measurement consecutive number. Each reconstructor's data points are fit with a constant (horizontal lines). **Right:** The Strehl ratio for Measurement 2, plotted against r_0, with fitted straight lines. The two points with highest Strehl and rather low r_0 are excluded from the fit (outliers).

5 Conclusion

We have tested two novel wavefront reconstructors, CuReD and HWR, using telescope simulator and on sky. Both algorithms ran stably in closed loop. In terms of the Strehl ratio, CuReD performs at least as well as the traditional least square method. HWR is slightly worse, which could be due to a problem with the mapping matrix (the problem has now been solved but the tests not yet repeated).

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