Alternative Methods for Acceleration of Wavefront Control Computation for Large Space Telescopes

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Objectives
The objective of this work was to investigate alternatives to hard real-time processing on onboard avionics and compute off-loading computation to co-processing boards. The baseline computational approach for HabEx and LUVOIR is to do these computations on-board with rad-hard processors. Even for a purely rad-hard design, more modern processors such as the RAD5545 should be preferred. On-board rad tolerant hardware approaches are too risky for on-board flight hardware given the Class A risk classification of flagship missions. The risks associated with limited on-board processing power with hard processors should be mitigable by one or more of the following approaches:

- offloading computation to the ground
- developing efficient HOWFS algorithms which are optimized to be either less memory intensive or more parallelizable, and increasing payload flight software risk tolerance to enable higher levels of compiler optimization or the use of off-the-shelf software libraries

Approach and Results
The approach taken was to invest heavily in framework which would be common for evaluation of both the baseline and the three alternatives. This framework included:

- off-loading computation to identify key wavefront sensing and control algorithms of current and potential future value
- Functional complexity evaluation of each of the key algorithms
- Literature and community research to identify the computational and memory capability of key processors that are candidates for future flight projects

This work was then used to build tools to parametrically evaluate performance for different use-cases (e.g. HabEx, LUVOIR) as a function of algorithm and processing architecture. With these tools we could combine the processor and memory capability with the computational complexity of the algorithms for an example case, and look at the time required to reach a nominal benchmark performance level. This analysis was also used to build link budgets for the evaluation of off-board computing architectures, the performance of which depends on distance and communications system assumptions.

Background
Future large telescope mission concepts such as HabEx and LUVOIR are baselining coronagraphic instruments with deformable mirrors and wavefront control systems to do high contrast imaging of exoplanetary systems with a goal of seeing reflected light from Earth-size planets around other nearby stars. These instruments will use larger deformable mirrors and larger focal-plane arrays than previous missions to take full advantage of the larger telescope apertures. High contrast imaging requires high order wavefront control algorithms that use those deformable mirrors to create areas with minimal starlight on those focal-plane arrays. Those algorithms have computational and memory costs which scale steeply with deformable mirror size; for an N^4 DM, we expect scalings of N^4 to N^6 in number of floating point operations and N^4 in storage requirements.

The baseline computational approach for HabEx and LUVOIR is to do these computations on-board with rad-hard parts. Unfortunately, rad-hard electronics capability lags commercial processor capability by a decade or more, and performing these computations on even near-future rad-hard processors may consume significant observation time for computation.

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The bulk of the computation time is spent on precomputation activities, which for either rad-hard or COTS parts will take from several days to several weeks of wall clock time. Per-iteration computation times are orders of magnitude smaller. This is consistent with JPL experience on Roman Coronagraph, where operational workarounds and FGPA acceleration of specific precomputation activity was only required to do the WFS precomputation in an acceptable time.

Significance/Benefits to JPL and NASA
Ground-in-the-loop (GITL) control is the best currently available alternative to on-board HOWFSC. Roman experience indicates that the iteration speed in GITL is primarily due to data transfer bottlenecks rather than computation time, early attention to ground system architecture in a GITL context could reduce delay considerably.

Co-processing in close orbits can accelerate computations to the point where HOWFSC computations no longer affect observation schedule. The co-processing mission may be developed at a lower risk level than the telescope, and COTS components can be upscreened for relatively low cost for use with a computational co-flyer architecture. Redundant spacecraft or replacement launches may be needed to keep the main telescope serviceable. If the GITL loop is set on a continuous but at lower cost versus the main bus. Novel algorithms such as adjoint-based EFC have potential for speedup but are not yet tested on space-borne processors. The use of compiler optimization, memory prefetching, and vectorization on-board could potentially improve estimates of computation time by at least an order of magnitude.

This work suggests that mission concepts with JPL involvement, such as HabEx, should start early definition of HOWFSC computational architecture, as high observation efficiencies will require computation strategies to be drivers of the overall system architecture rather than afterthoughts.

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Publications