A Modular Adaptive Vibrations Cancellation Scheme for SPARTA

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Vibration rejection in AO

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Mitigate the impact of vibrations on AO performance.
Adaptive and Modular

Why adaptive control?
- Attractive solution to reject perturbations with time-varying characteristics (Doelman et al. 2009, Beerer et al. 2012)
- Adaptive control for vibration rejection successfully applied in the context of stellar interferometry @ ESO telescopes (Di Lieto et al. 2008)

Why modular architecture?
- Easy to implement in existing control infrastructure
- Add-on functionality w.r.t. existing WF controller → no re-commissioning of existing controller needed
- Easily reconfigurable to different operational scenarios if required by the science case
- Modification of an algorithm proposed in Pigg et al. 2010

- Adaptive approach:
  - estimates online of the plant frequency response and the disturbance parameters → no prior knowledge of plant dynamics required
  - generates appropriate control signal to suppress vibration

- Both estimation and CSG work recursively at loop rate
- Can be operated in parallel to existing WF controller
Can be expanded including additional mechanisms to track on-line variations of vibration central frequency

Different frequency tracking algorithms can be implemented (PLL/EKF): PLL best trade-off between computational complexity and performance

AVC shares same philosophy (adaptive control) and fundamental structure (phase/amplitude estimator + PLL) with algorithm already tested on-sky @ Paranal

Equivalent to two 7x7 full MVM per cycle/vibration/mode → in line with RTC capability of MACAO-RTC and SPARTA
End-to-end Simulations

- ESO end-to-end tool OCTOPUS used to simulate addition & correction of vibrations
- GALACSI NFM LTAO simulated (4LGS + 1 NGS)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (unit)</th>
</tr>
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<tbody>
<tr>
<td>Time steps</td>
<td>5000</td>
</tr>
<tr>
<td>LGS sampling frequency</td>
<td>1000 Hz</td>
</tr>
<tr>
<td>NGS sampling frequency</td>
<td>200 Hz</td>
</tr>
<tr>
<td>LGS flux</td>
<td>80 photons/subaperture/frame</td>
</tr>
<tr>
<td>NGS flux</td>
<td>150 photons/subaperture/frame</td>
</tr>
<tr>
<td>LGS read noise</td>
<td>1e/pixel/frame</td>
</tr>
<tr>
<td>NGS read noise</td>
<td>15e/pixel/frame</td>
</tr>
<tr>
<td>Vibration 1 frequency</td>
<td>18 Hz (tip/tilt)</td>
</tr>
<tr>
<td>Vibration 2 frequency</td>
<td>48 Hz (tip/tilt)</td>
</tr>
<tr>
<td>Loop gain (of temporal integrator)</td>
<td>0.3</td>
</tr>
<tr>
<td>Delay</td>
<td>3 frames (1 for WFS integration plus 2 extra delay)</td>
</tr>
<tr>
<td>$r_0$</td>
<td>11.8 cm</td>
</tr>
<tr>
<td>PSF wavelength</td>
<td>0.65 µm</td>
</tr>
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GALACSI NFM LE Strehl @650nm for standard parameter set without vibrations = 0.073

Strehls with “bad conditions” vibrations @ 18Hz and 48Hz in both tip and tilt modes as measured on NACO added are:

<table>
<thead>
<tr>
<th></th>
<th>Without Pigg-Bodson</th>
<th>With Pigg-Bodson</th>
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<tbody>
<tr>
<td>LE Strehl at 650nm</td>
<td>0.047</td>
<td>0.070</td>
</tr>
<tr>
<td>Relative Strehl at 650nm</td>
<td>0.64</td>
<td>0.96</td>
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Almost all of the Strehl loss due to vibrations is recovered with AVC
Simulation results – NGS PSDs

- NGS slope PSDs (calculated from iterations 1000-5000)
- In x direction (y direction is analogous)

- Peaks at 18 & 48Hz almost entirely removed from NGS PSDs with AVC
Implementation in SPARTA AOF

Only Back-End of the real time box

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Alternative implementations regarding exec time

- **Typical AO loop control cycle**

- **Update AVC @ computation time**

- **Update AVC @ idle time (AVC one step ahead)**

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Alternative implementations regarding exec time

- F1=18Hz
- NGS loop @ 500Hz
- LGS loop @ 1kHz
- NGS measurements used to correct F1
- One additional sample delay included in the AVC path
- No additional information provided to the AVC
- No tuning modification performed
- AVC correction capability and convergence rate not affected by different implementation
Easy to reconfigure

- Correction in case of bright star (integration time 500Hz)
- Two vibrations (AR2 driven by white noise) @ 18Hz and 48Hz
- Longer integration time required in case of faint stars
- NGS measurements contain poor information regarding high frequency vibration
- If vibration propagates consistently in both loops → LGS signals could be used instead
Easy to reconfigure

- Longer integration time required in case of faint stars
- NGS measurements contain poor information regarding high frequency vibration
- If vibration propagates consistently in both loops $\rightarrow$ LGS signals could be used instead

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Easy to reconfigure

- F1=18Hz and F2=48Hz
- NGS loop @ 100Hz
- LGS loop @ 1kHz
- NGS signal used to reject vibration @F1
- Averaged LGS signal used reject vibration @F2
- Good correction of F1
- Good correction of F2 (looking @ LGS measurements)
- Residual vibration @F2 still visible in NGS (LGS lower SNR)
Conclusions

- Advantages of AVC:
  - Can cope with time-varying perturbations

- Methodology successfully tested in simulation
  - exploiting high fidelity AO loop E2E simulator
  - dedicated simulator

- Easy implementation in SPARTA control infrastructure

- Modularity enables enhanced operational flexibility:
  - Allows exploiting different measurement sources in different operational modes
Outlook

- **On-sky verification run on MACAO**
  - Feasibility analysis: processing of MACAO real time data to assess available stroke vs. amplitude of vibration to reject
  - Implementation and testing in MACAO simulator
  - On-sky verification of the algorithm

- Implementation of AVC user-interface and consolidation of bootstrap phase procedure

- Implementation in SPARTA and subsequent laboratory performance verification in the framework of AOF testing activity (ASSIST)

- Implementation/test for NAOMI and GRAVITY.