CURRENT STATUS OF RAVEN, A MOAO SCIENCE DEMONSTRATOR FOR SUBARU

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Abstract. Raven is a Multi-Object Adaptive Optics (MOAO) scientific demonstrator which will be used on-sky at the Subaru observatory from 2014. Raven is currently being built and tested at the University of Victoria AO Lab. This paper presents an overview of the optomechanical design and the software architecture of Raven, and gives the current status of this project. Raven includes three open loop wavefront sensors (WFSs), a laser guide star WFS and two figure/truth WFSs. Two science channels containing deformable mirrors (DMs) feed light to the Subaru IRCS spectrograph. Central to the Raven is a Calibration Unit which contains multiple sources, a telescope simulator including two phase screens and a ground layer DM that can be used to calibrate and test Raven in the lab. Preliminary results on calibration and open-loop AO correction using a tomographic reconstructor are presented.

1 Introduction

Raven will be the first Multi-Object Adaptive Optics (MOAO) science demonstrator on an 8 m telescope. Raven will be a visitor instrument at the NIR Nasmyth platform of Subaru feeding the IRCS NIR imaging spectrograph. Raven features three Natural Guide Star (NGS) and one Laser Guide Star (LGS) wavefront sensors (WFS), as well as two independent science channels. Raven is developed at the University of Victoria AO Lab in partnership with NAOJ and NRC.

2 Science goals

The main science requirements which drove the design of Raven are:

– Interface with IRCS spectrograph (\( \lambda = 0.9–4.1 \mu m, R = 100–20000 \)),
– Provide simultaneous spectroscopy:
  – Two science channels within a 2-arcminute field of view (FoV) are reimaged on IRCS slit (Fig. 1)
  – 4-arcsecond FoV per science channel
  – Position angles can be selected independently
– Achieve some multiplex advantage:
  – Ensquared energy \( \geq 30\% \) in 0.14-arcsecond slit
  – Throughput \( \geq 64\% \) in H band

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Fig. 1. Raven has three NGS WFS and one optional central LGS WFS. Raven can simultaneously feed the IRCS spectrograph with two distinct science targets.

- Needs some sky coverage:
  - Two to three NGSs brighter than magnitude R=15 are required within 3.5-arcminute FoV.
  - Zenith angle ≤ 60°
- Supported AO modes: MOAO, open-loop GLAO, closed-loop SCAO.

A science team, including astronomers from across Canada, Japan and the US, identified numerous science cases with actual targets suitable for Raven. So far, the main science cases are:

- Finding first stars,
- High redshift gravitationally lensed galaxies,
- Kinematic galaxy asymmetries,
- Kinematics of magnified galaxies in cluster fields,
- Stellar population of Maffei 1,
- Brown dwarfs,
- Proplyds in Orion and Rosette nebulae,
- Organic molecules in protoplanetary discs and exoplanet atmospheres

The Raven science team is open to new science cases and new collaborations.

2.1 Design overview

The optical block-diagram of Raven is depicted in Fig. 2. A CAD model of Raven is visible on Fig. 3. The major sub-system of Raven are:

- The Calibration Unit (built by INO) is a telescope simulator and turbulence generator to calibrate and test the system in the lab,
- Three Open-Loop (OL) WFSs: 10×10 subap 4.8-arcsecond FoV Shack-Hartmann using Andor iXon 860 EMCCDs,
- Two Science channels: each has a pick-off arm, a trombone, a 11×11 actuator ALPAO DM and an image rotator,
- A beam combiner to feed the IRCS slit,
Fig. 2. Raven functional block-diagram.

- Two Closed Loop (CL) WFSs for calibration and performance comparison,
- One optional on-axis LGS WFS to enhance performance and sky coverage,
- An acquisition Camera to display the whole FoV with the pickoff arms,
- A NIR Science camera for phase diversity and image quality assessment.

3 Current status

3.1 Hardware

All the opto-mechanical components are installed and aligned. Most of the electronics are mounted in the frame supporting the bench (Fig. 4a). Figure 4b shows a picture of the NGS and science target pickoff arms. The two science channels of Raven are visible on Fig. 5.

3.2 Software

The Raven Software is divided into four subsystems (Fig. 6):
- the User Interface,
- the AO Sequencer (AOS) controls all non-real-time hardware (motors, CU, Acquisition and Science Cameras). The AOS will also save all the data for telemetry,
– the Real-Time Computer (RTC) processes the WFS pixels and generates the DM commands,
– the RTC Parameter Generator (RPG) will update the tomographic reconstructor as the conditions change using the WFS data (SLODAR) or a model.

In May 2013, there were still some work to be done in terms of software:

– complete AO pipeline for all AO modes and calibration steps,
– implement correlation centroiding algorithm to increase the limiting magnitude,
– develop the SLODAR turbulence profiler,
– implement and test a dynamical zonal tomographic reconstructor with predictor or LQG controller [1],
– develop a science target selection and observation scheduling tool to maximise efficiency at the telescope,
– develop a phase-diversity algorithm using IRCS images to compensate non-common path aberrations (NCPA) between IRCS and Raven CL-WFSs.
Fig. 4. (a) The whole instrument in its enclosure and on the frame containing the electronics. (b) NGS and science pickoff arms.

Fig. 5. The two science channels implemented on the bench.
4 Lab tests and results

Raven is completely assembled in UVic AO lab. Pending the RTC, uncooled WFS cameras collect data at low frame rate using Matlab. The turbulence is played in slow motion to match the AO loop speed. This temporary setup allowed us to:

- fully calibrate the AO system (interaction matrices and offsets),
- test the different AO modes on bright asterism and get corrected images from the NIR science camera (Fig. 8),
- characterise the different sources of errors and compare them with the simulated error budget (Tab. 1),
- validate the static modal tomographic reconstructor.

Figure 7 plots a time series of the RMS wavefront error (WFE) measured by the CL-WFS of Raven during AO corrections for different scenarios. The chosen scenarios allow us to determine the amount of the different AO errors, such as WFS noise, open-loop errors (calibration and DM go-to error) and tomography error (Tab. 1).

Open-loop errors are greater than expected (146nm). We have some strategies to mitigate those errors such as using synthetic DM command matrices involving no SVD, and turning on the Figure sources of Raven to sense the actual DM shape.

The tomography error is in agreement with simulation, but further improvements are still expected with a zonal reconstructor and LQG controller.

Figure 8 displays a snapshot image of the science camera of Raven with and without AO correction. The slit of IRCS has been drawn on top of the image for comparison. The achieved image quality is pretty good and meet the 30%-ensquare energy requirement. It is worth noting that there is very little NCPAs between the CL-WFS and the NIR science camera, even without doing any phase diversity.

5 Next steps and schedule

The schedule of Raven project established in May 2013 is as follow:
Fig. 7. RMS wavefront error measured by the CL-WFS during 1 second of turbulence for different scenarios.

Table 1. AO error breakdown computed in nm rms from the quadratic differences of the measured WFE for different scenarios (Fig. 7).

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>Value</th>
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<tbody>
<tr>
<td>WFS &amp; bench noise ($\sigma_a$)</td>
<td>55</td>
</tr>
<tr>
<td>Open-loop error ($\sigma_b^2 - \sigma_a^2)^{1/2}$</td>
<td>227</td>
</tr>
<tr>
<td>Tomography error ($\sigma_c^2 - \sigma_b^2)^{1/2}$</td>
<td>172</td>
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- **July 2013**: First AO correction running at 500Hz with the RTC
- **Sep 2013**: RTC fully functional for all AO modes, with LGS WFS, DM tip-tilt offload, and pickoffs tracking the field rotation.
- **Oct-Nov 2013**:  
  - Perform all calibration steps and test all AO modes at 500Hz in the lab  
  - Measure AO performance for various asterisms and NGS magnitudes
- **Jan 2014**: Shipping to Hilo  
- **Mar 2014**: First engineering night at Subaru Telescope

**References**

1. Kate Jackson et al., these proceedings, (2013)
Fig. 8. Snapshot images obtained on the science camera of Raven for different AO modes. NGS asterism radius is 40 arcsec ($\lambda$=1.0-1.7 $\mu$m).