

Chapter 7

Summary, Conclusion and Future Scope of Work

The primary motivation of iRobo-AO is to rejuvenate the IUCAA Girawali Observatory 2-meter telescope with AO capability. iRobo-AO consists mainly uses off-the-shelf components and only a few custom-made ones; this makes it extremely cost effective. Also it will be for the first time AO is demonstrated in an Indian observatory. iRobo-AO is the second version of Robo-AO which was jointly built by California Institute of Technology, USA and Inter-University Centre for Astronomy and Astrophysics, Pune, India. It is a robust, laser-guided AO system; works with minimal overheads and provides good sky coverage, and hence will significantly enhance the scientific capabilities of small (1 to 3m class) telescopes by opening up the possibility of hitherto unavailable observational approaches. The AO system measures the atmosphere affected wavefront using a the Rayleigh LGS and corrects the wavefront distortions using a MEMS-based deformable mirror through a real-time closed loop feedback system. In the thesis, several considerations that are to be made to build an astronomical adaptive optics system are addressed. The comprehensive design and description of the iRobo-AO instrument with various tests and calibration results obtained in the laboratory are presented. This is a prerequisite before shifting it to the observatory and commissioning work.

Chapter 1 entitled Foundation of Adaptive Optics offers an introduction of the subject to pave the foundation before going into the design and development of the iRobo-AO for IUCAA 2m telescope. The blurring of images of celestial objects produced by ground-based telescopes is understood in the light of Kolmogorov

turbulence model. The Adaptive Optics based real-time correction technique is then discussed in detail with all the required building blocks. A brief review of a few AO systems and their performances are briefly presented.

The design and development of the Cassegrain AO facility which is the main AO unit is described in chapter 2 (Cassegrain AO Facility). The progress of the system development is discussed chronologically. The optical design, mechanical design, the optical integration, the cabling of the entire system and the testing of the AO loop are presented in this chapter. The design, specification etc. and the error budget are estimated. The optical performance of the system is described including, all the required optical and stroke size constraints required to ensure adaptive optics correction at IGO site are met. A method for reducing stray scattered light from reaching the WFS camera by gating the back scattered light of the LGS has been discussed, optical alignment of the crystal and gating performance tests in the laboratory are also elaborated. Finally we discuss the AO control law and how the corrected wavefront is reconstructed with some laboratory test results under various conditions. The slope telemetry files are analyzed and plotted, the AO correction is evident from the plots. About 70% reduction in the slope RMS deviation and about 80% reduction in the relative shift between the mean values of slope RMS in both X and Y are achieved with AO correction.

Wavefront sensing demands a bright guide star within the isoplanatic patch of the target star. This requirement is met wherever a Natural Guide Star (NGS) is not available, by using an artificial guide star produced using a laser (LGS). A description of the laser guide star system that uses a UV laser is given in chapter 3 (Laser Guide Star Facility). In this instrument, the laser is focused at 10 km above the telescope and produces guide star by Rayleigh scattering. The importance of on-axis projection is also discussed with simulation results and how this was achieved at IGO with the help of a periscope optics. The optical integration, the laboratory test results, electrical connection etc of the LGSF are also detailed in this chapter.

The effect of atmospheric dispersion effect in the AO system and its correction form the contents of chapter 4 (Atmospheric Dispersion Corrector). The Earth's atmosphere acts like a prism and introduces wavelength dispersion in the images of celestial objects observed through ground-based telescopes. The atmospheric dispersion elongates the image along the telescope elevation axis. i.e. normal to the horizon with the red end closer to the horizon and blue towards zenith. The

spot elongation becomes visible once the AO system shrinks the PSF. A Rotating type Atmospheric Dispersion Corrector (ADC) system is designed and developed for iRobo-AO with an adaptive atmospheric condition sensitive driving software module. Some laboratory test and modeling results under various atmospheric conditions are also presented. The ADC is designed to cope up with the atmospheric dispersion over the wavelength range 0.4 - 2.2 μm up to $\sim 65^\circ$ zenith angle. The design produces 11.4 μm rms spot radius, which is well within the 12 μm Airy disc radius. The rate of rotation of the ADC mounts to counter the effects of Cassegrain derotator have also been discussed.

Adaptive optics works better at infrared. Almost all the large telescopes have incorporated AO facilities. But these systems are expensive, need large design efforts and have high overheads which makes AO systems difficult to be made available on small and medium-sized telescopes. Robo-AO is designed to achieve cost effectiveness at a level that makes AO affordable for medium-sized telescopes. A compact and low weight NIR camera is built at IUCAA to extend the scientific capabilities of iRobo-AO and is covered in chapter 5 (Near Infrared (NIR) Camera Facility). The NIR camera deliver diffraction limited image quality over a 1.0' diameter field of view. It can be used to observe in J, H, K, Ks and K' bands. The optics matches Nyquist sampling in all the bands on the 18 μm detector pixels. The entire optics is well shielded from heat source contaminations. A detector controller, ISDEC along with the associated hardware, firmware and software provides hassle-free operation. It also allows users to carry out quick characterization of the H2xRG detector. The the camera is integrated with Linux based observatory control software. The NIR camera can also be used as a tip-tilt camera to measure the atmospheric tip-tilt while the science observation is being made to be in the visible regime using the visible EMCCD camera.

After the design and development process followed by laboratory integration and testing, the instrument was installed on the 2m telescope at IUCAA Girawali Observatory (IGO). The installation steps are elaborated in chapter 6 (Commissioning). The entire commissioning process is divided into three phases; the first one is the installation of the laser projector, the second one is the installation of Cassegrain AO box with LGS alignment, and the last phase is the running the AO loop followed by the calibration of the entire system. The first phase is described in the laser guide star chapter. The Cassegrain box AO facility has been installed at the Cassegrain port and all the electronic controllers, computers etc. at the side

ports of the telescope. The telescope altitude and Cassegrain axes were balanced in this configuration.

Alignment of the Cassegrain AO unit with the telescope (pupil matching) is done by tweaking the elliptical fold mirror (FM1) to have the telescope pupil at the center of the DM. The LGS is then aligned to the telescope by observing the pupil illumination and the formation of the LGS. Finally, defocused spots produced by the Shack-Hartman lenslet array are aligned with CCD39.

Scope for future work

- The UV array of spots at the CCD39 appears defocused; this is from low altitude Rayleigh scattering. A variable diaphragm at the intermediate image plane of LGS in front of OAP5 to blocks stray Rayleigh scattered light will stop this fogging at the SHWFS. The aperture size can be adjusted by observing the best output at the CCD39. The diaphragm may be mounted on an X-Y translating stage. The Shack-Hartmann lenslet spots are to be placed at the center of 6×6 pixel boxes of CCD39 by adjusting the last lens of the relay lens system after focusing the LGS. The Pockel cell need to be integrated with the water cooling system to enable fast (10kHz) laser pulse rate. The ADC and Retarder systems have to be calibrated and the entire system performance evaluated on sky.
- The design of the AO system can be improved further as follows.
 - As the Deformable Mirror (DM) technologies progress, the actuator dynamic range may become sufficient for atmospheric tip-tilt and high order aberration compensation with a single system. This will eliminate the requirement for the tip-tilt stage and two OAPs (OAP2 and OAP3) along with two flat mirrors. Otherwise, DM can be placed on a tip-tilt stage and the OAPs and flat mirrors can be removed. This is not only cost effective but reduces reflection loss, non-common path error etc. But there will be an additional tip-tilt in the WFS arm in the LGS beam due to the atmospheric tip-tilt correction by the DM which is common in both WFS and science path. This leads to the motion of LGS spots at the WFS plane. To counteract this issue one can introduce the same angle to the FSM to bring back the LGS at the center of WFS.

- Simultaneous atmospheric tip-tilt correction and science observation can be done in real time by non-destructive reading of HAWAII detector. The centroid shift of a natural guide star can be calculated from the subtracted frame between two consecutive readouts of the HAWAII detector.
- One of the potential strengths of the system is its ability to carry out large surveys using robotic operation of iRobo-AO with queue scheduling, which enhances capability and efficiency. Full robotization of the system requires integrating with the telescope control system and observatory control system. This will greatly enhance the capabilities of the observatory by allowing to perform time-domain astronomy through queued operation of iRobo-AO, which will enable repeated, high cadence observations of scheduled targets. The system will then also be able to respond quickly with follow up observations of transient events like gamma-ray bursts, supernovae etc.