

Development of a precision satellite-laser ranging optics for ultra-long-distance measurement

Hyug-Gyo Rhee (hrhee@kriss.re.kr), Pilseong Kang, Jaehyun Lee, Han-Gyol Oh
Length & Dimensional Metrology Group, Korea Research Institute of Standards and Science (KRISS)

Abstract

Artificial satellites have been launched by many countries. Consequently space debris has increased rapidly, causing problems in space operations. To determine these space object's movement paths and their coordinates, a precision length measurement from ground to the space objects is required. The length & dimensional metrology group in KRISS recently has been developed a satellite-laser-ranging optics, which measure the distance to a satellite. In this paper we will introduce out design concept, optics fabrication, and an AI-based alignment scheme for out SLR optics.

Approach

Design & optical alignment scheme

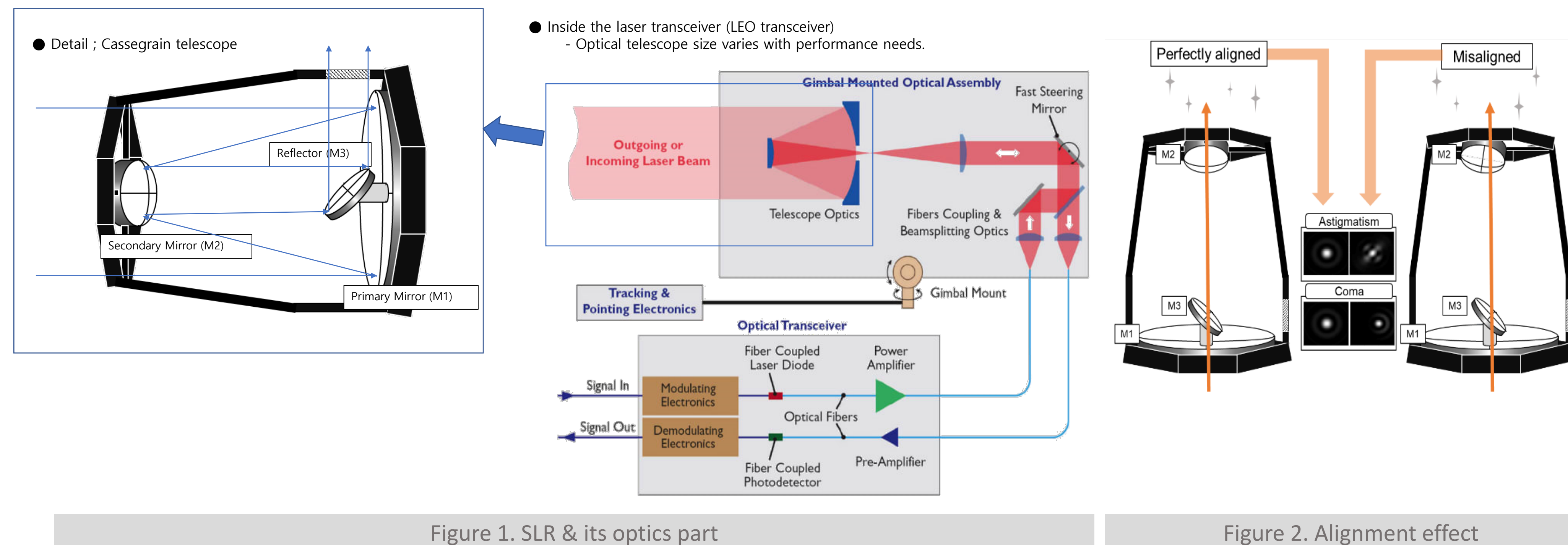


Figure 1. SLR & its optics part

Figure 2. Alignment effect

Precise alignment of large SLR optics(telescope) is essential for achieving high performance. For example, for a Cassegrain telescope, star images before and after alignment can appear as shown in Fig. 1 & 2. Various tools and techniques for aligning large telescopes have been developed continuously over time. In particular, laser trackers have been widely used for initial rough alignment, facilitating efficient positioning of optical elements. Separately, interferometry has been applied for fine alignment, achieving high precision in minimizing residual error. Our research combined both methods into a single workflow to produce optimized results for large optical telescopes. We present a two-step alignment approach that combines the use of a laser tracker for rough alignment and interferometry for fine alignment, integrated with the RMS WFE method. The ability to predict the final alignment state without physically moving the compensator is suitable for large optical system alignment, as physical adjustment can be inconvenient and time-consuming.

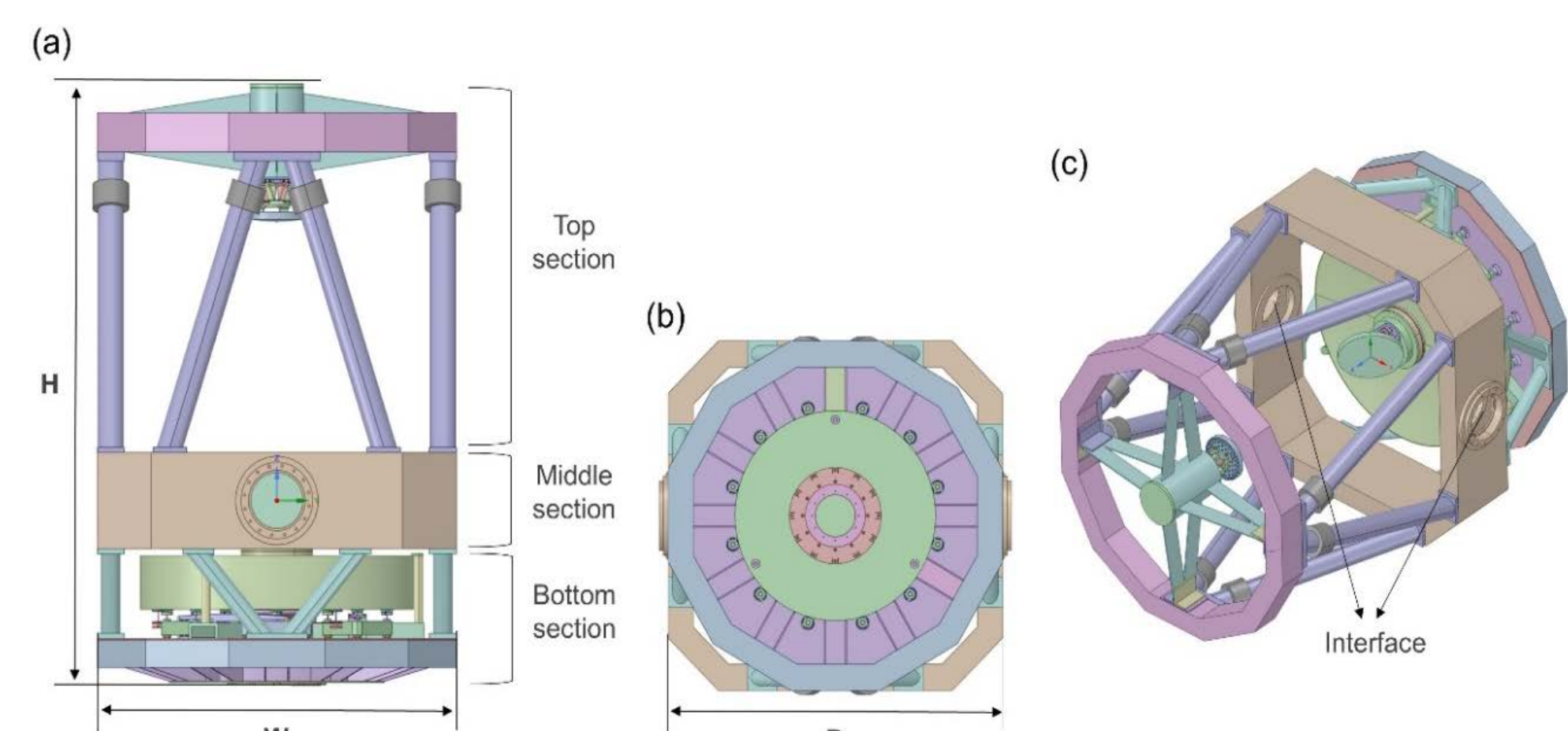


Figure 3. Configuration of our SLR optics. (a) Front, (b) top, and (c) isometric views. W: width, H: height, D: depth

Figure 3 shows the overall configuration of our optics that employs the A-shaped Serrurier scheme to reduce the structural deformation. The sizes are approximately 4 m in height, 2 m in width, and 2 m in depth. The optics consists of the three parts: bottom, top, and middle section. The bottom frame holds the primary mirror (M1) assembly of which the aperture size is approximately 1.5 m. The top frame holds the secondary mirror (M2) assembly consisting of the M2, supporting mounts, and a hexapod. The clear aperture size of the M2 is approximately 0.3 m and the spider vane connects the M2 assembly to the OTA frame. The top and bottom frame have a dodecagonal shape and the four bipod trusses connect them to the middle frame.

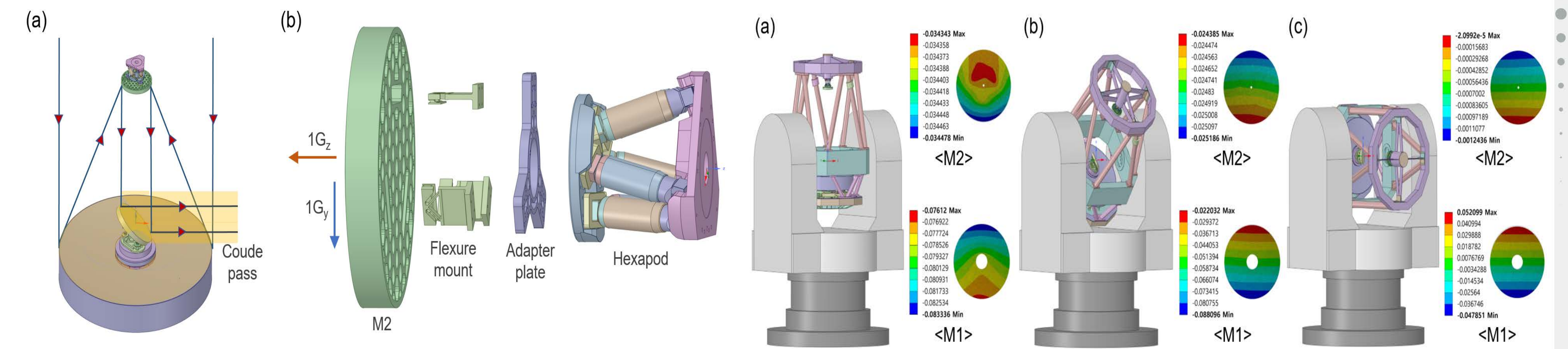


Figure 4. M2 assembly design for active alignment

Figure 5. Light weight pattern design for M2

Figure 4 is the configuration for optical path and M2 assembly. It consists of the M2, flexure mount, adapter plate and hexapod. The red and blue arrows represent the gravity directions in the vertical and horizontal directions, respectively. Figure 5 shows the The surface deformations of the M1 and M2 due to SLR optics' deflection.

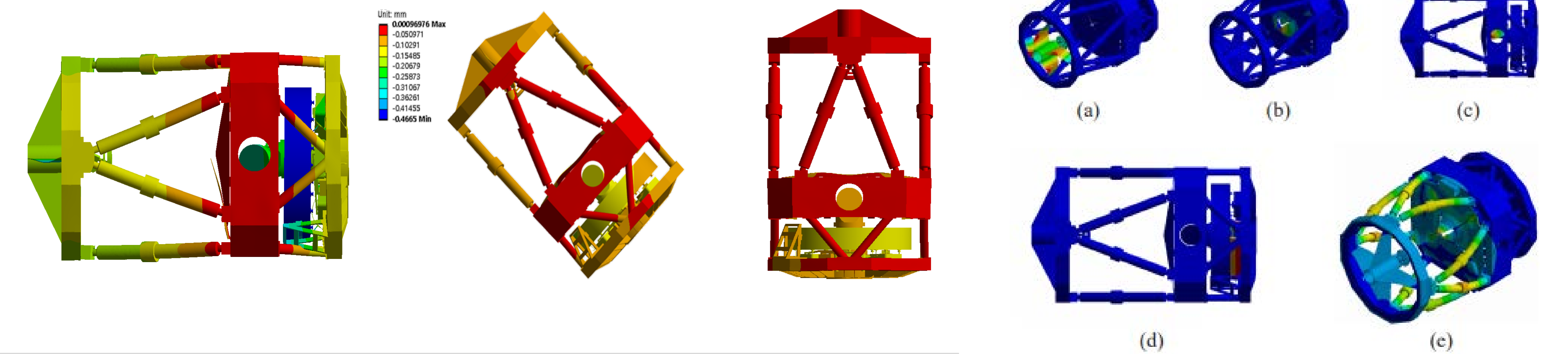


Figure 6. Deflections and relative displacement of the optics with various potitions

Figure 7. Mode shapes and natural frequencies

From the modal-analysis results, the mode shapes are broadly classified into four local mode shapes (spider vane, cover, M1 mount, and M3 assembly) and global mode shapes for the OTA, as shown in Fig. 7. Fig. 7 (a) Local mode-spider (23.8 Hz), (b) local mode-cover (23.9 Hz), (c) local mode-M1 mount (38.9 Hz), (d) local mode-M3 assembly (131.8 Hz), and (e) global mode-OTA (98.9 Hz).

Results & conclusions

Two-step scheme with AI algorithm

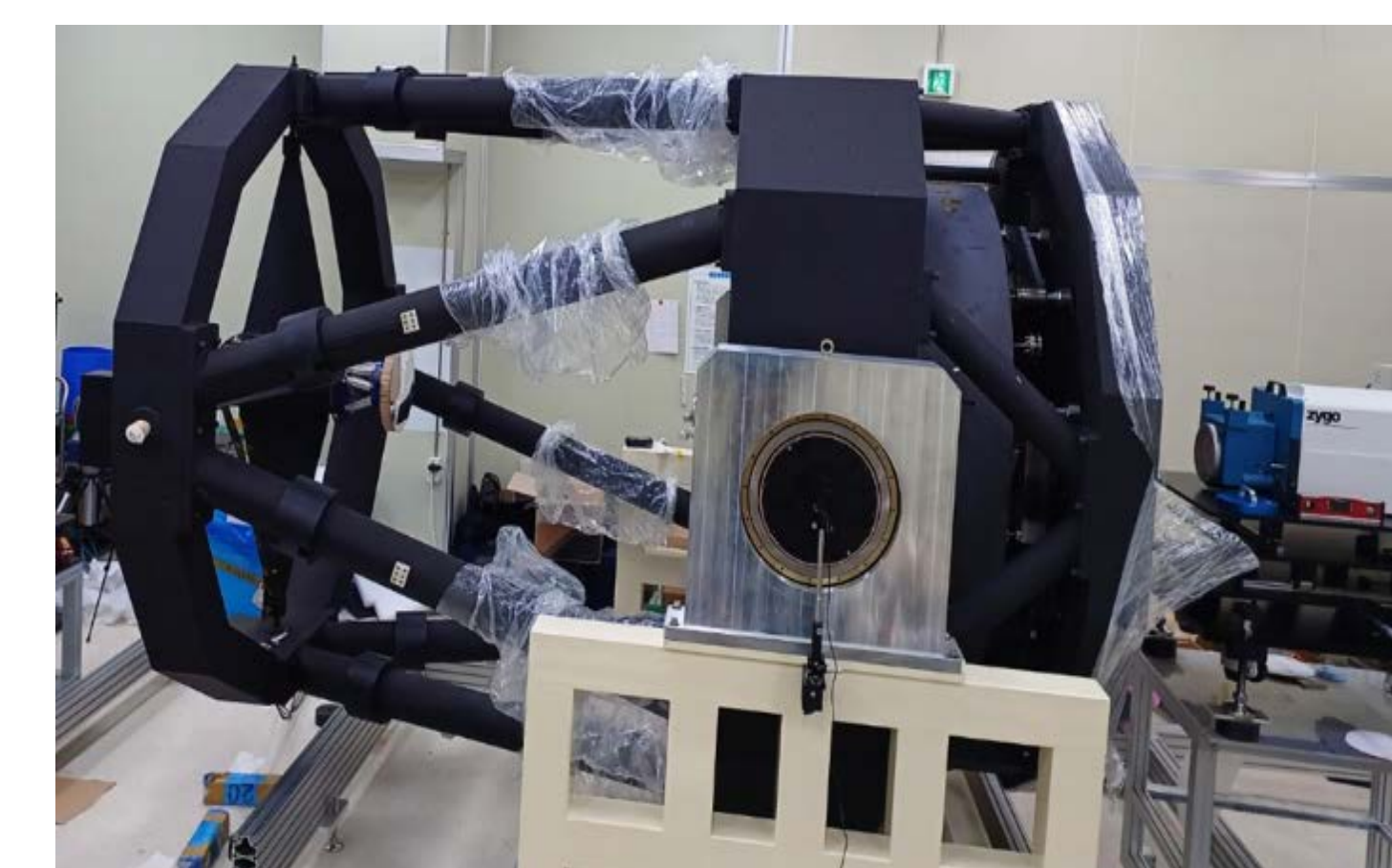


Figure 8. Alignment setup by using a Fizeau interferometer

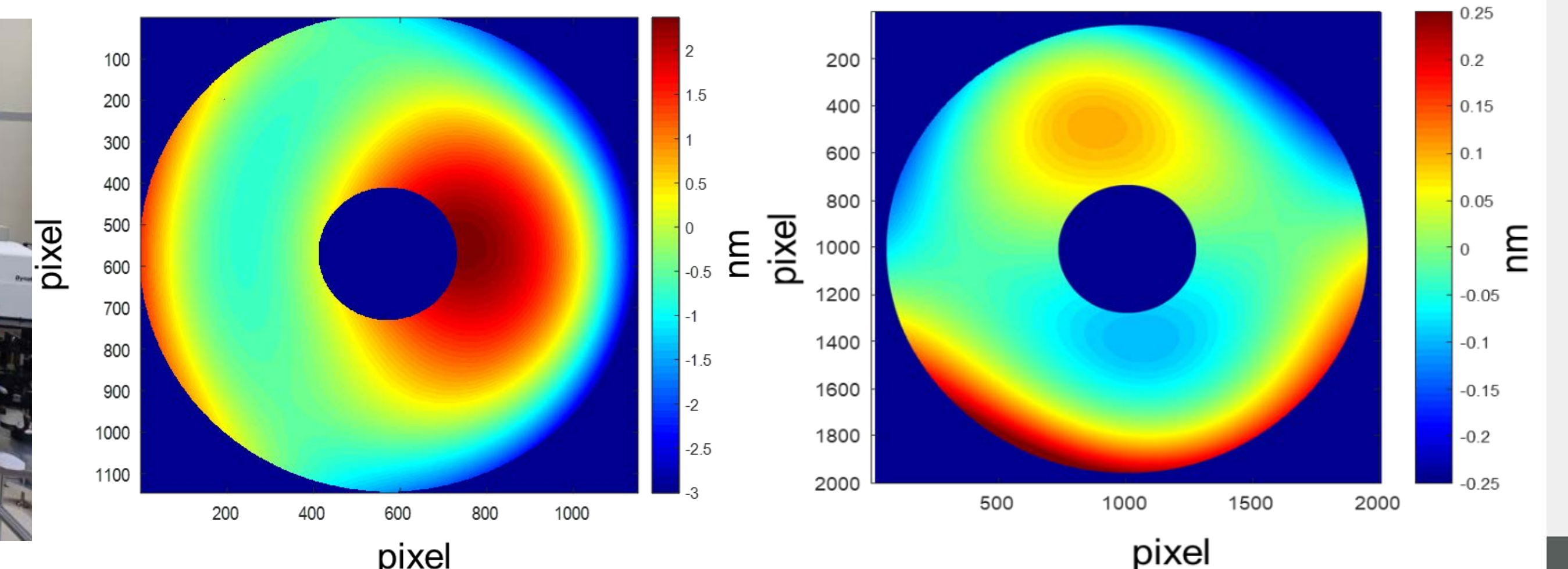


Figure 9. (a) Initial(WFE 644 nm rms), (b) After alignment with AI algorithm (WFE 54 nm rms)

Figure 8 & 9 shows the interferometer measurements after the initial alignment with the laser tracker. In the second alignment step, we apply the RMS wavefront error (WFE) method, which uses the RMS WFE value as an additional boundary condition during the optimization process. The alignment results show that we achieved an rms value of 49.03 nm, satisfying the development goal.

Reference

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