Active Optical Zoom for Tracking

Ty Martinez[1], Freddie Santiago[1], David V. Wick[2], Brett E. Bagwell[2], Sergio R. Restaino[1], Christopher C. Wilcox[1], Jonathan R. Andrews[1], Don M. Payne[3]

[1]Naval Research Laboratory
[2]Sandia National Laboratory
[3]Narrascape

ABSTRACT

In order to optically vary the magnification of an imaging system, continuous mechanical zoom lenses require multiple optical elements and use fine mechanical motion to precisely adjust the separations between groups of lenses. By incorporating active elements into the optical design, imaging systems that are capable of variable optical magnification with no macroscopic moving parts are possible. Changing the effective focal length and magnification of an imaging system can be accomplished by positioning two or more active optics in an optical design. In this application, the active optics (deformable mirrors) serve as variable focal-length lenses and steering mirrors making an active optical zoom system that can zoom in on off-axis points on the image and therefore track objects in the field of view of the system. We will present results from a bench top system.

1. INTRODUCTION

Active and adaptive optics are playing an ever-increasing role in imaging and laser projection applications. Over the last 30 years, deformable mirrors have revolutionized the imaging capability of astronomical observatories[1]. Nearly every major observatory in the world utilizes some sort of adaptive optical system in a closed-loop architecture to compensate aberrations caused by turbulence in the atmosphere. The success of adaptive optics in correcting atmospheric aberrations has sparked interest in the technology for other applications, such as improving the flexibility and capabilities of imaging systems while reducing size, weight and potentially cost. In cases where closed-loop feedback is not used, the broader term "Active optics" is often more appropriate[1]. Active optics can be used to adjust the diffraction-limited FOV of an imaging system very quickly without macroscopic moving parts,[8-9] and we have investigated using both liquid crystal (LC) spatial light modulators (SLMs) and deformable mirrors (DMs) as active optics to achieve this nonmechanical zoom.

Tracking sytems typically have a wide field of view acquisition system and then hand off tracking to a narrow field of view system. Speed, size, weight and power requirements have likely limited or completely prohibited the use of mechanical zoom lenses in tracking applications.

A zoom lens is simply an optical system that can vary magnification or focal length while keeping the image plane stationary. Conventional technology requires a continuous zoom lens to have multiple optical elements and uses coupled motion to adjust the axial separations between individual or groups of elements in order to vary the FOV of the system[2]. Mechanical zoom lenses such as those found on 35 mm cameras may take hundreds of milliseconds to vary magnification and are restricted to magnifying the area on-axis (i.e. the system must be directly pointed at the area to be magnified). Discrete, multiple FOV systems have been developed that vary magnification by rotating lenses or groups of lenses in and out of the optical path, and these are also limited to on-axis magnification.

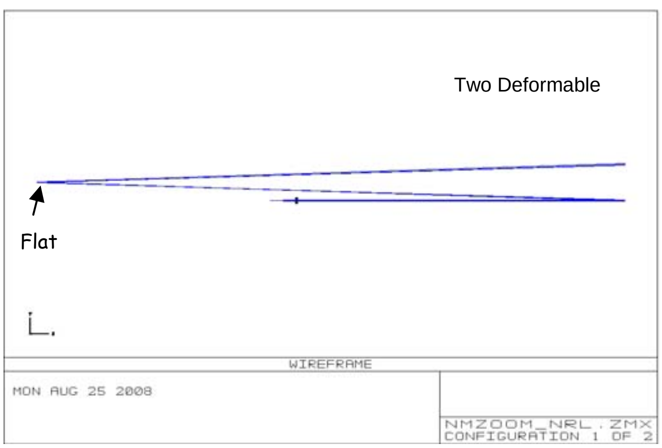
In order to magnify an area-of-interest that is not initially on-axis, gimbals are often used to redirect the instantaneous FOV of an imaging system. Gimbals, however, often weigh as much as the entire optical system, and depending on the size of the optics and the speed of the gimbal, they can draw hundreds or even thousands of Watts to slew large-aperture systems. Even state-of-the-art gimbals take hundreds of milliseconds to slew large angles and may induce unwanted jitter or require momentum compensation.

In order to achieve true optical zoom and gimballess tracking/steering while overcoming deficiencies in size, weight, and power requirements, we are proposing a revolutionary alternative to conventional mechanical zoom systems where moving lenses/mirrors and gimbals are replaced with active optics. Nonmechanical zoom (a.k.a. active optical zoom) could allow a laser communication system to change its FOV in real-time without macroscopic motion. It would also be capable of tracking or slewing within the wide FOV of the system without physically moving. Thus, a nonmechanical zoom system could reduce or even eliminate the need for a gimbal in a tracking system.

Active or adaptive optics, such as liquid crystal (LC) spatial light modulators (SLMs) and deformable mirrors (DMs), have previously been proposed and demonstrated as variable focal-length elements[3-5]. Focus control is accomplished by systematically adjusting the optical path across the element to add/subtract quadratically varying phase. In fact, any aberration can be added or subtracted (focus is simply a low order aberration), providing a tremendous amount of flexibility.[6-7] By applying the appropriate voltage to each pixel or actuator, the optical path can be adjusted to create an optical wavefront that approximates the wavefront produced by a conventional lens (SLM) or mirror (DM). By changing those voltages appropriately, the "focal length" of the active element can be varied within the limits set by the dynamic range and the number of pixels or actuators.

These active optics can be integrated into a conventional optical design to create a zoom imaging system that does not require macroscopic moving elements[8-10]. By appropriately designing the system, these variable focal-length elements can provide the flexibility necessary to change the overall system focal length, and therefore FOV, that is normally accomplished with mechanical motion. In addition to changing the focal length of an active optic, optical tilt can also be added to the wavefront by appropriately adjusting the voltages. This allows magnification of or slewing to any point within the FOV without physically moving some portion of the optical system.

2. Current Setup



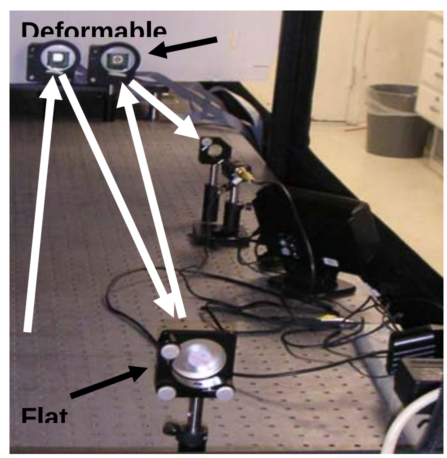


Figure 1. Zemax lens design layout and experimental layout on the optical bench.

Figure 1 is a ZEMAX design and setup on the optical bench of two Deformable Mirrors (DMs) from OKO technologies. These mirrors have a variable focal length from infinity to 1.4m. Light comes in and strikes the DM on the left which then directs light to the static flat mirror (located in front facing the two DMs) and is then redirected to the second DM. The light then goes to a lens and finally to the camera. The system is controlled from a single computer and power supply which control the two deformable mirrors and capture images from the camera. In Figure 2 we see some preliminary results using the system showing a 4X zoom. The next step is to train the mirrors for different field angles so that we will be able to track an object and zoom in where needed to continue tracking the object.

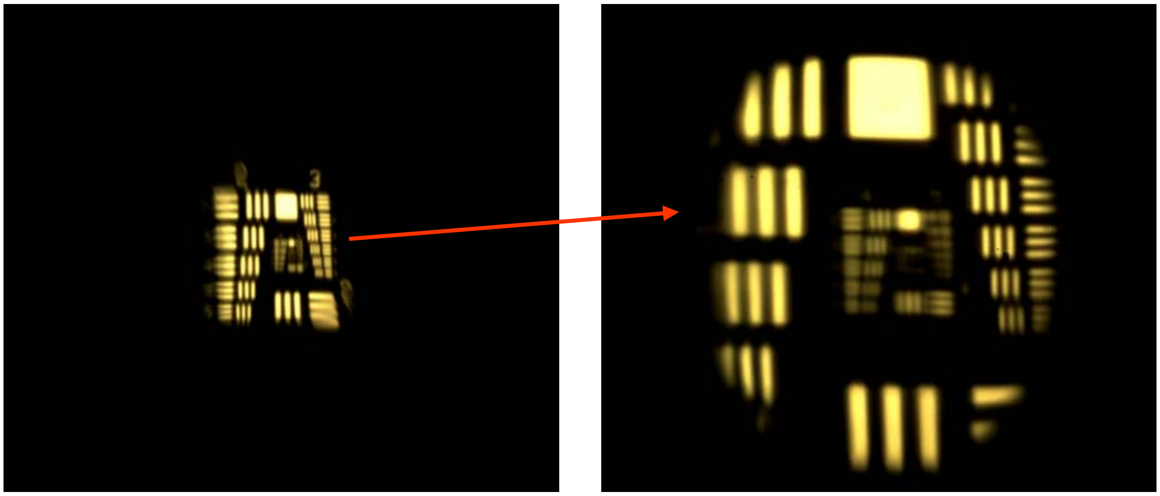


Figure 2. Preliminary results from the system showing a 4X zoom.

3. Characterization or training of Mirror

In Figure 3 is our AO testbed with aberration generator. The DM is replaced with one from the nonmechanical zoom system and the aberration generator is programmed with the inversed of desired surface and then the AO software is run which forces the DM to put the desired shape and our mirror is programmed.

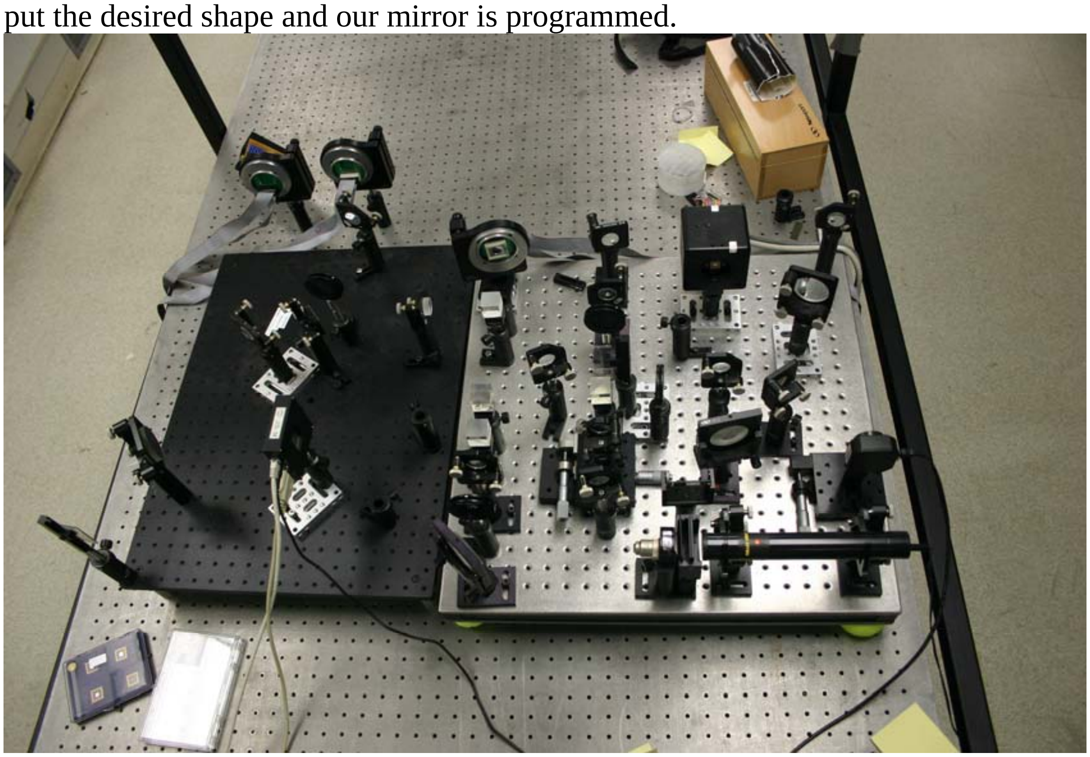


Figure 3. Adaptive optic testbed with aberration generator which is used to train the DMs for the nonmechanical zoom.

4. Future

The current system and previous nonmechanical zoom systems we have built have always characterized the mirror and the simply applied the corrections but had no wavefront sensor in the system to adjust for misalignments or dynamic aberrations. The next step is to include a Shack-Hartmann wavefront sensor in the system to correct for static and dynamic aberrations. This system will be similar to our AO system however with the two DMs in the system we will need to include an algorithm which will choose which DM to use to do the final correction.

5. Conclusions

We have shown how a nonmechanical zoom system with about a 4X zoom may be used to track an object within its field of view without the use of gimbals. This has the potential to eliminate the problems associated with gimbals when tracking. In the future we plan to add a wavefront sensor to our system to allow compensation of misalignments and dynamic aberrations.

REFERENCES

1. R. K. Tyson, *Principles of Adaptive Optics,* Second Edition, Academic Press, San Diego (1998).
2. See for example, M. Laikin, *Lens Design, Second Edition*, pp. 301-365, Marcel Dekker, Inc., New York (1995) or R.R. Shannon, *The art and science of optical design,* pp. 533-553, Cambridge University Press, New York (1997).
3. A. F. Naumov, G. Love, M. Y. Loktev, and F. L. Vladimirov, "Control optimization of spherical modal liquid crystal lenses ," *Opt. Express* **4**(9)**,** 344-352 (1999).
4. V. Laude, "Twisted-nematic liquid-crystal pixilated lens," *Opt. Comm*. **153**, 134-152 (1998).
5. Y. Takaki and H. Ohzu, " Liquid-crystal active lens: a reconfigurable lens employing a phase modulator," *Opt. Comm*. **126**, 123-134 (1996).
6. G. D. Love, "Wave-front correction and production of Zernike modes with a liquid-crystal spatial light modulator," *Appl. Opt*. **36**, 1517-1524 (1997).
7. D. M. Pepper, C. J. Gaeta, and P. V. Mitchell, "Real-Time Holography, Innovative Adaptive Optics, and Compensated Optical Processors Using Spatial Light Modulators," Chap. 14 in *Spatial Light Modulator Technology - Materials, Devices, and Applications,* U. Efron, ed., Marcel Dekker, Inc., New York (1995).
8. D.V. Wick and T. Martinez, "Adaptive optical zoom," *Opt. Eng.*, **43**, 8-9 (2004).
9. T. Martinez, D.V. Wick, D.M. Payne, J.T. Baker, and S.R. Restaino, "Non-mechanical zoom system," *Proceedings of the SPIE*, **5234**, 375-378 (2003).
10. E.C. Tam, "Smart electro-optical zoom lens," *Opt. Lett*. **17**, 369-371 (1992).