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Find the *Adaptive Optics Associates WFS-01-EM* at our website: *Click HERE*

WaveScope® Applications

Adaptive Optics and Mirror Control

Deformable Mirror Control

A deformable mirror has a surface shape that can be altered to control wavefront phase. The main technologies currently available are summarized in Table 1. In order to control a mirror in a known way it must be calibrated to determine the effect of each actuator, or combination of actuators, on the shape of the surface. A wavefront resconstructor is produced that can be used to calculate the drive signals required for closed loop control of the mirror. AOA's WaveScope wavefront sensor with the adaptive optics option controls deformable mirrors and automatically calculates these wavefront reconstructors.

Mirror	Actuator
Thin Glass	Discrete axial piezoelectric actuators produce local displacement.
Bimorph	Sheets of piezoelectric material bonded to a thin mirror control the local curvature.
Membrane	Metal membrane whose global curvature is controlled by electrostatic forces.
Segmented	Array of rigid mirrors with tip, tilt and piston actuators.

Table 1. Types of Deformable Mirrors

Mirror Flattening

With the actuators at their zero position a deformable mirror is not necessarily flat. Connected to the mirror drive electronics via a series of communications cables (RS 422 in the case of a Xinetics deformable mirror), WaveScope will flatten the deformable mirror (see *Figure 1*). The first step in the process is to move each actuator and record its effect on the wavefront phase. Those that deviate the phase by less than a predetermined threshold value and any that have no effect on the mirror's shape (actuators that fall within obscurations) are excluded from the calculation of the wavefront reconstructor. The actuator motion and wavefront phase information collected is used to set up a series of equations for which a generalized inverse is found using the mathematical technique of Singular Value Decomposition. The resulting wavefront reconstructor relates wavefront phase to actuator motion.

WaveScope's adaptive optics option calculates both zonal and modal reconstructors. Parameters of the mirror control loop may also be changed to optimize convergence. Other reconstructors can be written in the Tk/Tcl scripting language.

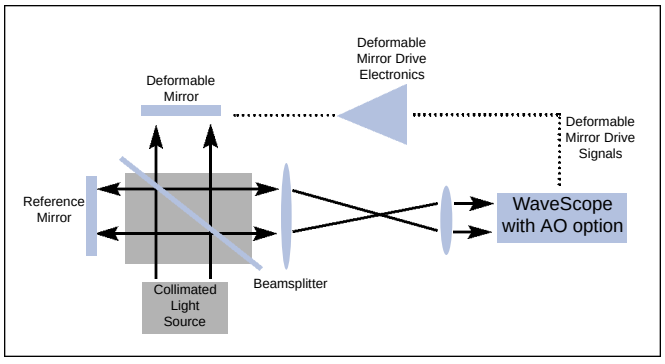


Figure 1. Deformable Mirror Flattening

Atmospheric Adaptive Optics

A typical atmospheric adaptive optics system is shown in *Figure 2*. Light from a distant object is collected by a telescope and divided between a wavefront sensor and an imaging camera. The wavefront sensor measures the wavefront phase and, using a reconstructor, calculates the mirror drive signals required to remove the aberrations caused by the atmosphere. A CCD camera, steering mirror, deformable mirror, and dedicated wavefront processor are incorporated into the system. The wavefront is measured at 1KHz rates so that closed loop control is achieved at 100 Hz

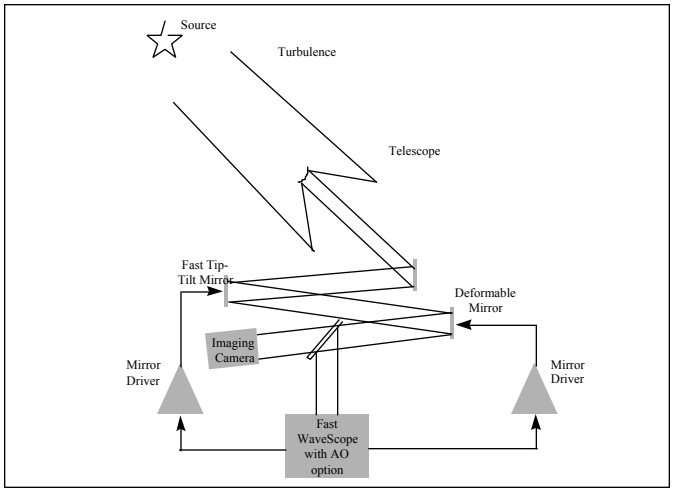


Figure 2. Atmospheric Adaptive Optics.

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Adaptive Optics Associates, Inc.
Ten Wilson Road
Cambridge, MA 02138

Tel:617-806-1400
Fax:617-806-1899
info@aoainc.com
www.AdaptiveOptics.com

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WaveScope® Applications

Optical Testing of Flat Surfaces

General Description

WaveScope is a Shack Hartmann wavefront sensor. Like an interferometer it measures wavefront phase, and so it can be used to test optical surfaces. *Figure 1* shows an optical set up to measure a surface with respect to a flat reference mirror. The set up is very similar to a Twymann-Green interferometer where lenses are used to image the surfaces of both the test and reference onto WaveScope's lenslet array. The lenses also scale the test pupils by a magnification equal to the ratio of their focal lengths, F_2/F_1.

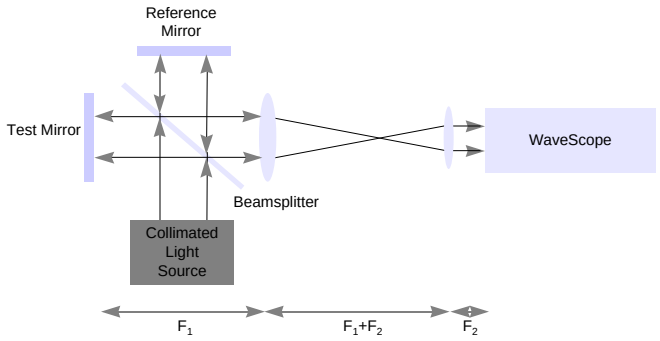


Figure 1. Flat Mirror Testing

Alignment

WaveScope's pupil imaging capability makes alignment of the test and reference easy. In "Alignment Mode" move WaveScope's camera to image the pupil plane. The relay lenses can now be adjusted to both collimate the light and produce a well focused image at WaveScope's entrance

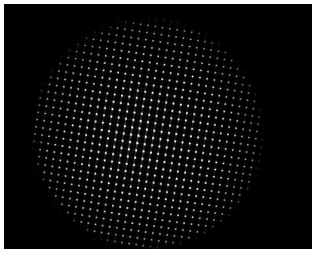


Figure 2. Reference Pupil

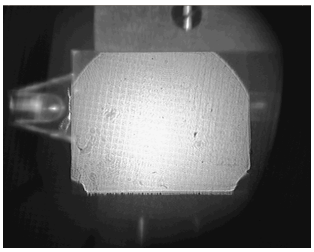


Figure 3. Test Pupil

pupil as shown in *Figures 2 and 3.* Any large tilts are removed from the reference by using the WaveScope's "Show Tip Tilt" mode. This moves the camera between the pupil and Hartmann spot planes. Large tilts are present if the spots move relative to the lenslet subapertures. These are removed by adjusting the tilt of the reference mirror. A similar procedure is used to align the test surface. Final adjustments are made by looking at the interference fringes in the pupil plane when light from both surfaces is allowed to enter WaveScope simultaneously. The test surface is adjusted to produce the broadest possible fringes thus removing tilts between the test and reference surfaces.

Calibration

WaveScope is calibrated by measuring the positions of the Hartmann spots off the reference mirror. To do this, light from the test surface is blocked and WaveScope's "Calibration" routine is started. WaveScope records the positions of the subapertures in the pupil plane and the spots in the Hartmann image plane. When prompted for the "Test Source", cover the reference mirror and uncover the test surface. Once the test data has been taken WaveScope steps the user through pupil definition and even allows the graphical editing of subapertures. Reference and aberrated test spot patterns are shown in *Figures 4 and 5.*

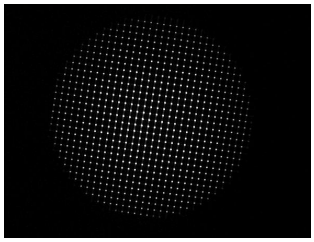


Figure 4. Reference Spots

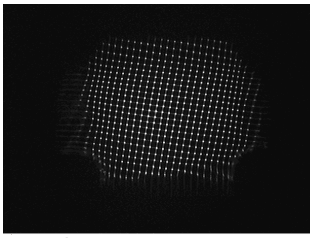


Figure 5. Test Spots

Measurements

The user can select from a number of factory tests or create custom tests to include up to 20 optical parameter displays. Once the test has been opened the "Execute" mode allows real time data display, saving of data and the adjustment of data taking and averaging parameters. Two of WaveScope's optical parameter displays are shown below.

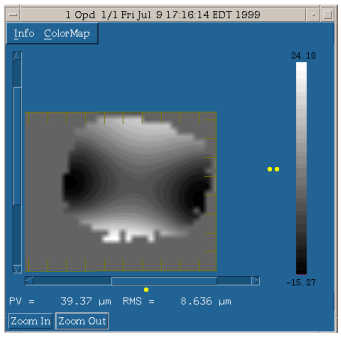


Figure 6. Optical Path Difference Map

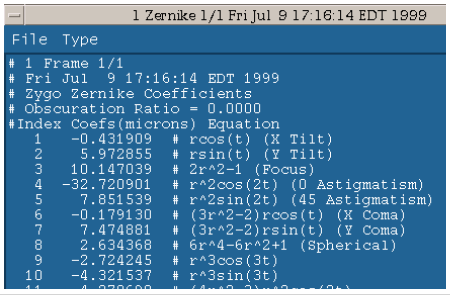


Figure 7. Zernike Polynomials

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Cambridge, MA 02138

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Fax:617-806-1899
info@aoainc.com
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WaveScope® Applications

Deformable Mirror & Adaptive Optics Options

Features

Controls Xinetics deformable mirrors
Controls OKO deformable mirrors
Uses standard PC computers
Derives wavefront reconstructors
Saves and recalls actuator settings
Tk/Tcl scripting



241 Actuator Mirror Nominal Surface



241 Actuator Mirror Flattened Surface

Applications

Optical aberration removal
Atmospheric adaptive optics
Laser cutting and drilling
Retinal imaging
Laser communications
Remote sensing



Adaptive Optics with WaveScope

AOA's WaveScope product line is a range of wavefront sensors to solve demanding optical measurement problems. However, WaveScope is more than just a wavefront sensor; it can also control deformable mirrors in closed loop adaptive optics systems. The AO option turns WaveScope into a complete adaptive optics system with a 37 actuator micro-machined deformable mirror, interface electronics, adaptive optics software, reference optics, and collimated laser source. WaveScope's DM option consists of the 37 actuator micro-machined deformable mirror, interface electronics, and adaptive optics software. DM-XIN-xxx is a PC control interface for a xxx actuator Xinetics deformable mirror. When installed on a WaveScope computer with adaptive optics software, it is used to flatten the deformable mirror. Such a WaveScope adaptive optics system is routinely used by *Lockheed Martin Missiles and Space* to flatten a 241 actuator deformable mirror to an RMS wavefront error of less than λ/25 at 915 nm.

Implementation

A number of ISA cards are installed in the WaveScope computer to communicate with the deformable mirror drive electronics.

For Xinetics mirrors, each card controls up to 64 actuators and comes with cables that connect directly to the mirror drive electronics. The software calculates reconstructors, allows either manual or computer control of the mirror, and saves actuator positions for recall at any time.

Reconstructors

To control a deformable mirror in a closed loop, a wavefront reconstructor must be derived. WaveScope automatically moves each mirror actuator and records the effect on the wavefront. This produces a matrix that relates actuator motions to wavefront. This matrix is inverted using Single Value Decomposition to find a transformation matrix that relates wavefront to actuator motion.

Custom Systems

AOA has a history of excellence in adaptive optics and has delivered many systems to government, academic, and commercial customers. An example is ALFA, an astronomical adaptive optics system that AOA built for the Max-Planck Institute for Astronomy's 3.5 meter Calar Alto telescope. If you need high performance adaptive optics for beam control, laser communications, or image enhancement, please call with your requirements.

AO	37 actuator micro-machined deformable mirror, interface electronics, adaptive optics software, optical bench, reference mirror, beamsplitters, collimated HeNe laser, far field imaging camera, monitors.

DM	37 actuator micro-machined deformable mirror, interface electronics, adaptive optics software.
DM-XIN-xx	Interface electronics, cables and control software for xxx actuator Xinetics mirror.

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info@aoainc.com
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WaveScope® Product Line

Wavefront Sensors and Adaptive Optics

Introduction

The WaveScope product line is a complete range of Shack-Hartmann wavefront sensors to solve your most demanding measurement problems. Whether you need extended wavelength range, spatial resolution, or frame rate, AOA has a wavefront sensor to meet your needs.

Extended Wavelength Ranges

WaveScope has a number of camera and optics options to meet your wavelength requirements. For UV and visible applications AOA offers CCD cameras and fused silica or epoxy lenslet arrays. Infra-red sensitive CCD, InSb, InGaAs or pyroelectric cameras and KRS5, ZnSe or IR epoxy lenslet arrays are available for measurements beyond 1.0 mm.

Fast Frame Rates

In astronomical adaptive optics and laser communications camera speed and sensitivity are often the factors that determine the overall performance of a wavefront sensing system. For these situations AOA has systems that use fast, multiple readout CCDs and real time analysis with multiple processor configurations based on PCI or VME buses.

External Event Triggering

It is often necessary to synchronize wavefront data capture to an external event, such as a laser pulse. Several versions of WaveScope support external event triggering, and WaveScope has versions that cover the most widely used laser wavelengths.

Adaptive Optics

All of AOA's wavefront sensors can control deformable mirrors in closed loop adaptive optics systems. The AO and DM WaveScope options add a deformable mirror and control software to any WaveScope wavefront sensor. The wavefront analysis and mirror drive signal calculations are performed with Pentium processors running AOA's WaveScope software and the Tk/Tcl scripting language. The DM-XIN-xxx is a PC interface and control software for a xxx actuator Xinetics mirror.

Model Number	Wavelength Range [nm]	Lens Pitch [µm]	Lens Array Format	Frame Rate [Hz]	Camera Bits	External Trigger	Exposure Control	Application
WFS-01	400 - 1064	480 300 190	20 x 20 32 x 32 72 x 72	30	8	no	yes	Optical component measurement. CW laser wavefront and beam profile. Low bandwidth adaptive optics.
WFS-UV	193 - 400	300	32 x 32	30	8	no	yes	Optical component measurement. Excimer laser wavefront and beam profile.
WFS-mini	400 - 1064	250 190	20 x 20 26 x 26	30	8	no	yes	Low cost wavefront phase measurements. IR and UV versions available.
WFS-IR1	900 - 1700	480 300 190	20 x 20 32 x 32 72 x 72	30	8 or 12	yes	yes	Pulsed laser wavefront and beam profile of Nd:YAG and soild state communications lasers
WFS-IR2	2000 - 20,000	call	call	30	8 or 10	yes	yes	Mid IR laser wavefront and beam profile. Wavefornt phase of CO_2 lasers.
WFS-F1	400 - 1064	call	call	490	12	yes	yes	Pulsed visible laser wavefront, Ti:sapphire. Medium bandwidth adaptive optics.
WFS-F3	400 - 1064	call	call	700	8	yes	yes	Astronomical adaptive optics and laser communications.
AO	With a WaveScope sensor makes a complete adaptive optics system. Includes an optical bench, far field imaging camera, monitors, collimated HeNe laser, reference mirror, beamsplitters, and a 37 actuator micro-machined deformable mirror with drive electronics, power supplies, and control software.							Closed loop adaptive optics. Laser wavefront control.
DM	37 actuator micro-machined deformable mirror with drive electronics, power supplies, and contol software.							Closed loop adaptive optics. Laser wavefront control.
DM-XIN-xxx	PC Interface electronics and control software for Xinetics xxx actuator mirror							Mirror flattening and control

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Ten Wilson Road
Cambridge, MA 02138

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Fax:617-806-1899
info@aoainc.com
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WaveScope®

WFS-01

Precision Wavefront Phase and Beam Profile

Features

- Replaces interferometers and beam profilers
- Vibration Insensitive
- Wavelength range from 400 to 1064 nm
- Works with monochromatic and white light
- Large dynamic range, 400λ P to V @ 633 nm
- Accurate to λ/100 RMS @ 633 nm
- Pentium PC with Linux or Windows NT®
- Easy to use graphical interface
- Tk/Tcl scripting language
- Adaptive optics option

Applications

Lens and mirror testing
Laser wavefront measurements
Process and quality control
Optical alignment
Control of deformable mirrors and adaptive optics
Turbulence measurements
Beam profiling

How It Works

WaveScope is a Shack-Hartmann wavefront sensor. It replaces interferometers and beam profilers and works at any wavelength from 400 to 1064 nm. WaveScope uses a purely geometric phase measurement technique; it works with both coherent and incoherent light and is insensitive to vibration. Using the adaptive optics option, WaveScope also actively controls wavefronts to remove aberrations.

To measure the local wavefront gradient, a lenslet array divides the incoming wavefront into a set of spatial samples, called subapertures, and forms an array of spots. A lens then relays the spots onto a CCD camera.



A change in the gradient of the wavefront across a subaperture will produce a shift in position of the spot. By measuring these small shifts, the local gradient of the wavefront is measured. By translating the camera and relay lens along the optical axis, WaveScope takes data in both the pupil and spot planes. This allows spots to be tracked across several subapertures giving large tilt dynamic range. It also ensures accurate mapping of positions on the wavefront into the spot plane and measures the illumination in the pupil plane. From the array of wavefront gradients, WaveScope calculates standard optical wavefront parameters.

Wavefront Software and Tk/Tcl

WaveScope comes with AOA's wavefront analysis software. Through the graphical user interface WaveScope is aligned and calibrated to a reference wavefront. Data can be displayed, stored, and recalled for further analysis in numerous formats. With the Tk/Tcl scripting language, users can access AOA's WaveScope atomic functions and write specialized data reduction procedures.

Aperture	10 mm diameter
Frame rate	30 Hz
Pupil shape	circular, rectangular, obscured
Wavelength range	400 to 1064 nm
Wavefront sampling	20 x 20, 32 x 32, 72 x 72
Gradient accuracy	λ/20 P to V @ 633 nm
Full aperture tilt range	400λ P to V @ 633 nm
RMS wavefront error	λ/100 @ 633 nm

Exposure control	1/60 to 1/10,000 second
Data collection	30 Hz burst, wavefront averaging
Output	ASCII, binary, FITS, TIF, GIF, BMP, PS, JPG, Code V and Zemax compatible Zernikes. Wire, contour and text displays.
Measurements	Spot images, gradient vectors, OPD, PSF, MTF, encircled energy, fringes, beam profile, laser beam quality, Zernike, monomial, Seidel, Hermite, Chebychev and Legendre polynomials.

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Cambridge, MA 02138

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mini-WaveScope®

WFS-mini

Low Cost Wavefront Phase and Beam Profile

Features

- Replaces interferometers and beam profilers
- Vibration Insensitive
- Wavelength range from 400 to 1064 nm
- Works with monochromatic and white light
- Large dynamic range, 80λ P to V @ 633 nm
- Accurate to λ/100 RMS @ 633 nm
- Pentium PC with Linux or Windows NT®
- Easy to use graphical interface
- Tk/Tcl scripting language
- Adaptive optics option

Applications

Lens and mirror testing
Laser wavefront measurements
Process and quality control
Optical alignment
Control of deformable mirrors and adaptive optics
Turbulence measurements
Beam profiling

How It Works

Mini-WaveScope (WFS-mini) is a low cost wavefront sensor. It measures only 46 x 40 x 64 mm and weighs approximately 200 g. This makes mini-WaveScope ideal for situations where accurate wavefront phase and intensity measurements are required in tight spaces and harsh environments. Using the adaptive optics option, mini-WaveScope also actively controls wavefront phase to remove optical aberrations.

To measure local wavefront gradient mini-WaveScope uses the Shack-Hartmann technique. A lenslet array divides the incoming wavefront into a set of spatial samples, called subapertures. Light from these subapertures is focused to an array of spots on a CCD camera.



A change in the gradient of the wavefront across a subaperture will produce a shift in position of the spot. Therefore, by measuring these small shifts the gradient of the wavefront is measured with a spatial resolution equal to that of the lenslet array. From this array of gradients mini-WaveScope calculates standard optical wavefront parameters.

Wavefront Software and Tk/Tcl

Through the graphical user interface mini-WaveScope is aligned and calibrated to a reference wavefront. Data is displayed, stored and recalled for further analysis in numerous formats. Image windows can be sent to a printer or stored in standard image formats. Data arrays are stored as ASCII or binary and Zernike outputs are compatible with Code V, Zygo, and Zemax.
Mini-WaveScope also comes with the Tk/Tcl scripting language and the user can write specialized data reduction procedures.

Aperture	5 mm diameter
Frame rate	30 Hz
Pupil shape	circular, rectangular, obscured
Wavelength range	400 to 1064 nm
Wavefront sampling	20 x 20, 26 x 26
Gradient accuracy	λ/20 P to V @ 633 nm
Tilt dynamic range	80λ P to V @ 633 nm
RMS wavefront error	λ/100 @ 633 nm

Exposure control	1/60 to 1/10,000 second
Data collection	30 Hz burst, wavefront averaging
Output	ASCII, binary, FITS, TIF, GIF, BMP, PS, JPG, Code V and Zemax compatible Zernikes. Wire, contour and text displays.
Measurements	Spot images, gradient vectors, OPD, PSF, MTF, encircled energy, fringes, beam profile, laser beam quality, Zernike, monomial, Seidel, Hermite, Chebychev and Legendre polynomials.

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Cambridge, MA 02138

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UV WaveScope®

WFS-UV

Wavefront Phase and Beam Profile from 193 to 400 nm

Features

- Replaces interferometers and beam profilers
- Vibration Insensitive
- Wavelength range from 193 to 400 nm
- Works with monochromatic and white light
- Large dynamic range, 200λ P to V @ 633 nm
- Accurate to λ/100 RMS @ 633 nm
- Pentium PC with Linux or Windows NT®
- Easy to use graphical interface
- Tk/Tcl scripting language
- Adaptive optics option

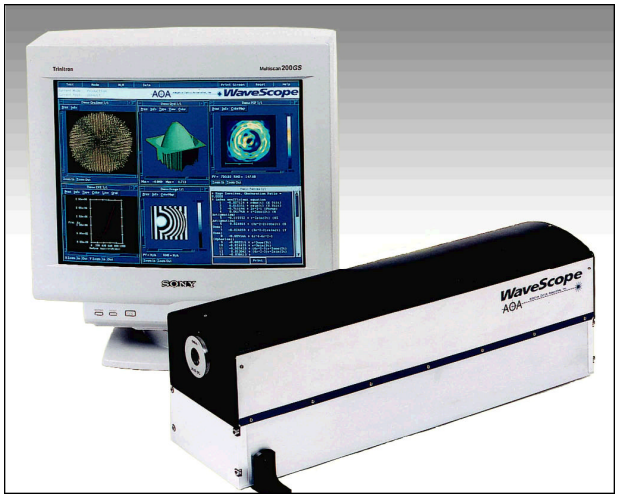
Applications

Lens and mirror testing
Laser wavefront measurements
Process and quality control
Optical alignment
Control of deformable mirrors and adaptive optics
Turbulence measurements
Beam profiling

How It Works

Fused silica optics and a windowless CCD give UV WaveScope sensitivity from 193 to 400 nm, making it particularly suited to the measurement of excimer laser wavefront phase. Using the adaptive optics option, UV WaveScope also actively controls wavefronts to remove aberrations.

To measure local wavefront gradient, UV WaveScope uses AOA's extended Shack-Hartmann technique. A lenslet array divides the incoming wavefront into a set of spatial samples, called subapertures, and forms an array of spots. A lens then relays the spots onto a CCD camera. A change in the gradient of the wavefront across a subaperture will produce a shift in position of the spot.



By measuring these small shifts, the local gradient of the wavefront is measured. By translating the camera and relay lens along the optical axis, UV WaveScope takes data in both the pupil and spot planes to allow spots to be tracked across several subapertures, giving UV WaveScope large tilt dynamic range. It also ensures accurate mapping of positions on the wavefront into the spot plane and measures the illumination in the pupil plane. From the array of wavefront gradients, WaveScope calculates standard optical wavefront parameters.

Wavefront Software and Tk/Tcl

UV WaveScope comes with AOA's wavefront analysis software. Through the graphical user interface, UV WaveScope is aligned and calibrated to a reference wavefront or optical surface. Data can be displayed, stored and recalled for further analysis in numerous formats. Users can access AOA's UV WaveScope atomic functions and write specialized data reduction procedures in the Tk/Tcl scripting language.

Aperture	10 mm diameter
Frame rate	30 Hz
Pupil shape	circular, rectangular, obscured
Wavelength range	193 to 400 nm
Wavefront sampling	32 x 32
Gradient accuracy	λ/50 P to V @ 633 nm
Full aperture tilt range	200λ P to V @ 633 nm
RMS wavefront error	λ/100 @ 633 nm

Exposure control	1/60 to 1/10,000 second
Data collection	30 Hz burst, wavefront averaging
Output	ASCII, binary, FITS, TIF, GIF, BMP, PS, JPG, Code V and Zemax compatible Zernikes. Wire, contour and text displays.
Measurements	Spot images, gradient vectors, OPD, PSF, MTF, encircled energy, fringes, beam profile, laser beam quality, Zernike, monomial, Seidel, Hermite, Chebychev and Legendre polynomials.

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IR WaveScope®

WFS-IR

Wavefront Phase and Beam Profile from 0.9 to 1.7µm

Features

- Replaces interferometers and beam profilers
- Vibration Insensitive
- Wavelength range from 0.9 to 1.7 µm
- Works with monochromatic and white light
- Large dynamic range, 400λ P to V @ 633 nm
- Accurate to λ/100 RMS @ 633 nm
- Pentium PC with Linux or Windows NT®
- Easy to use graphical interface
- Tk/Tcl scripting language
- Adaptive optics option

Applications

Lens and mirror testing
Laser wavefront measurements
Process and quality control
Optical alignment
Control of deformable mirrors and adaptive optics
Turbulence measurements
Beam profiling

How It Works

IR WaveScope (WFS-IR1) uses an uncooled InGaAs camera that has excellent response from 0.9 to 1.7 mm. Therefore, it is particularly suited to the measurement of wavefronts from the short wave infra red laser diodes used in laser communications. Using the adaptive optics option, IR WaveScope also actively controls wavefronts to remove aberrations.

To measure the local wavefront gradient, a lenslet array divides the incoming wavefront into a set of spatial samples, called subapertures and forms an array of spots. A lens then relays the spots onto a CCD camera. A change in the gradient of the wavefront across a subaperture will produce a shift in position of the spot.



By measuring these small shifts, the local gradient of the wavefront is measured. By translating the camera and relay lens along the optical axis, IR WaveScope takes data in both the pupil and spot planes. This allows spots to be tracked across several subapertures giving large tilt dynamic range. It also ensures accurate mapping of positions on the wavefront into the spot plane and measures the illumination in the pupil plane. From the array of wavefront gradients, IR WaveScope calculates standard optical wavefront parameters.

Wavefront Software and Tk/Tcl

IR WaveScope comes with AOA's wavefront analysis software. Through the graphical user interface IR WaveScope is aligned and calibrated to a reference wavefront or optical surface. Data can be displayed, stored, and recalled for further analysis in numerous formats. With the Tk/Tcl scripting language, users can access AOA's IR WaveScope atomic functions and write specialized data reduction and display procedures.

Aperture	10 mm diameter
Frame rate	30 Hz
Pupil shape	circular, rectangular, obscured
Wavelength range	0.9 to 1.7 µm
Wavefront sampling	20 x 20, 32 x 32, 72 x 72
Gradient accuracy	λ/20 P to V @ 633 nm
Full aperture tilt range	400λ P to V @ 633 nm
RMS wavefront error	λ/100 @ 633 nm

Exposure control	1/60 to 1/10,000 second
Data collection	30Hz burst, wavefront averaging
Output	ASCII, binary, FITS, TIF, GIF, BMP, PS, JPG, Code V and Zemax compatible Zernikes. Wire, contour and text displays.
Measurements	Spot images, gradient vectors, OPD, PSF, MTF, encircled energy, fringes, beam profile, M-squared, Zernike, monomial, Seidel, Hermite, Chebychev and Legendre polynomials.

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