Real-Time Wavefront Sensing at High Resolution with Electrically Tunable Lens

A phase camera is an instrument that can simultaneously measure the intensity and wavefront aberrations of the incoming light, turning this data into thorough maps. As technology evolves, there's a growing need to use the highest possible resolution within the largest possible field of view. Wooptix introduces a compact real-time high-resolution phase camera able to simultaneously recover wavefront phase distortions and the intensity of an optical field.

Aberrations in optical systems can be detected using data and maps obtained from wavefront measurements. Without them, telescopes wouldn't be able to overcome the atmosphere distortion to observe distant stars, and laser corrective eye surgeries wouldn't exist. Over time, the field of applications for wavefront sensors has expanded to include manufacturing, and even communications systems, with more on the way. To answer these ever-growing needs, Wooptix has developed a phase camera that uses an electrically tunable lens (ETL) to obtain data from two out-of-focus images in symmetrical planes, before and after the focal point. This allows for minimum capture time and avoids a mechanical system between the camera or the sample.

Incorporating computer imaging into wavefront sensing

In the world of metrology and imaging, Shack-Hartmann sensors are the industry standard. Although widely used in adaptive optics for their ability to measure discrete wavefront slopes, they have a critical limitation. Lateral resolution, the level of detail, is always limited by the number of lenses in the device. A higher lateral resolution means a better ability to distinguish two separate objects next to each other. This and other limitations show that microlens sensors will soon struggle to meet the newer and more demanding needs of industries that are moving into smaller dimensions.

SEBI® RT1000 wavefront sensor takes an innovative approach to these challenges. It first captures two out-of-focus images on either side of the pupil plane, and then recovers their phase gradients along two directions perpendicular to the lightbeam. The sensor then compares them using Wooptix's proprietary algorithm to calculate the wavefront slope and apply the necessary corrections. With this method, there is no need for mechanical translation or prism stages. Almost imperceptible defects in the surface of lenses, such as scratches, can be detected quickly and with high precision.

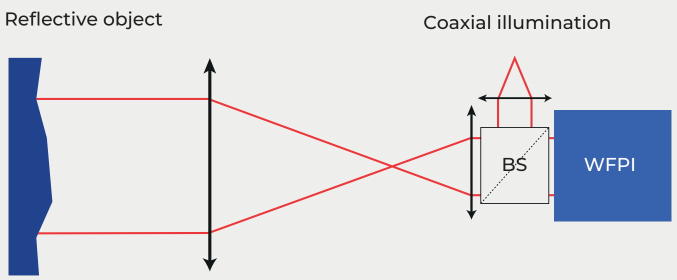

Figure 1. Basic implementation for reflective objects

In our wavefront sensor design, the ETL is a key component that enhances the acquisition process, but it excels when coupled with a computational approach. Thanks to Wooptix's image processing technique, the device only contains the lenses and the detector, maintaining a simplified design delivered in a compact form.

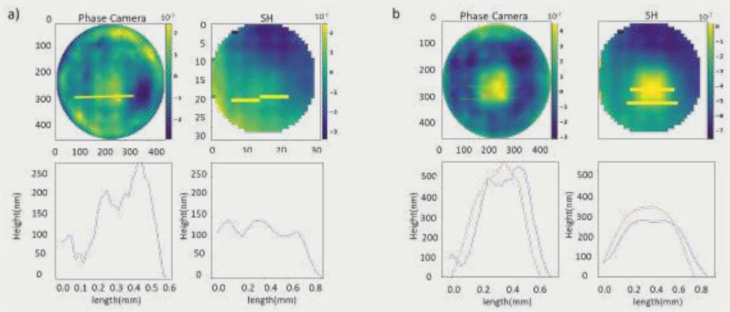

Figure 2. (a) R shape depicted with the deformable mirror; phase camera allows for detection of the actuator positioned at 0, opposite to the SH sensor. (b) Line in the DM measured at different zones. Different colors in the charts represent a distinct cross-section profile.

This approach allows to change the propagation distance quickly and automatically, enabling real-time measurements in areas where it is critical. An example of an application is microscopy, where the objects under investigation are constantly changing their behavior, characteristics, and position. It is therefore desirable to see their immediate response to the introduction of a new element into the sample.

Side-by-side performance comparison with an industry standard wavefront sensor

To guarantee that the SEBI® RT1000 meets the highest quality standards, its performance was benchmarked against that of a conventional microlens wavefront sensor. To ensure an accurate evaluation of the behavior of both devices, a deformable mirror was used to compare the results.

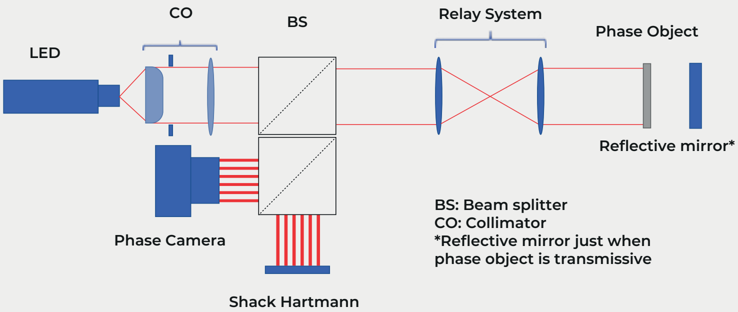

Figure 3. Setup to compare the Shack-Hartmann sensor with SEBI® RT1000

The initial test involved measuring the height of the mirror's actuators. To ensure accuracy, the heights were calculated using the data provided by the mirror's manufacturer and the voltage variations were converted into nanometers. The results showed that the microlens sensor detected an incorrect height of 364 nm, while the SEBI® RT1000 provided a value of 532 nm, which was extremely close to the manufacturer value of 525 nm. This demonstrates the ability to detect high-frequency details with an increased lateral resolution, as well as more precise phase images.

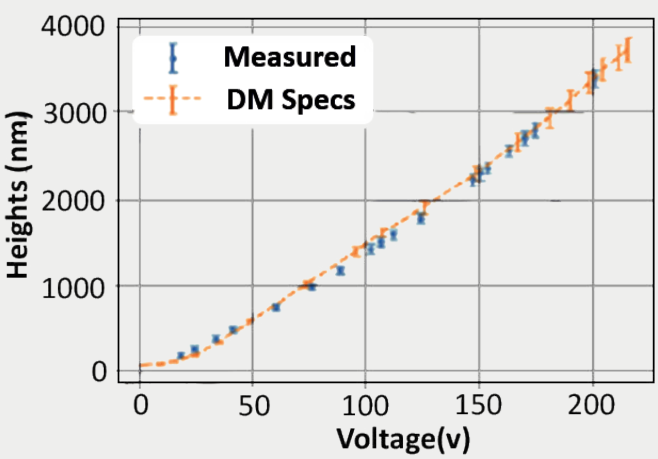

Figure 4. Deformable-mirror study comparison with the measured values of the proposed apparatus. Volt unit in the abscissa; the DM used allows from 0 to 220 volts.

In standard microlens sensors, minor alterations in width or height are contingent upon the number and dimensions of the microlenses. This presents a challenge that the SEBI® RT1000 has successfully addressed, enabling the sensor to achieve a higher level of detail while maintaining its compact shape.

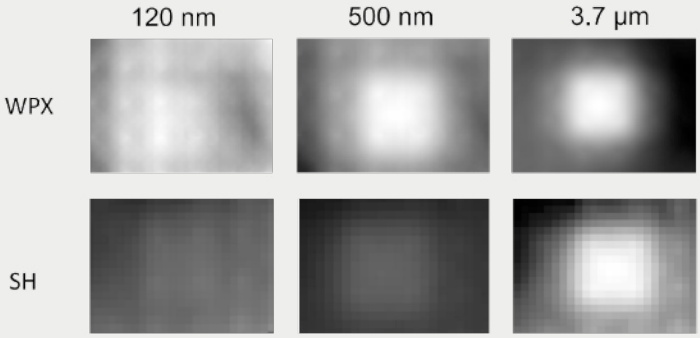

Figure 5. Observation of the mirror pistons using both sensors

The capabilities of the SEBI® RT1000 were also evaluated by characterizing several lenses with varying degrees of astigmatism. The results confirmed that the sensor can readily adapt to different configurations and experimental conditions, aligning with the specific requirements of the user. Additionally, the test demonstrated the SEBI® RT1000's capacity to measure diverse astigmatism angles, multiple diopters, and high frequencies within the lens.

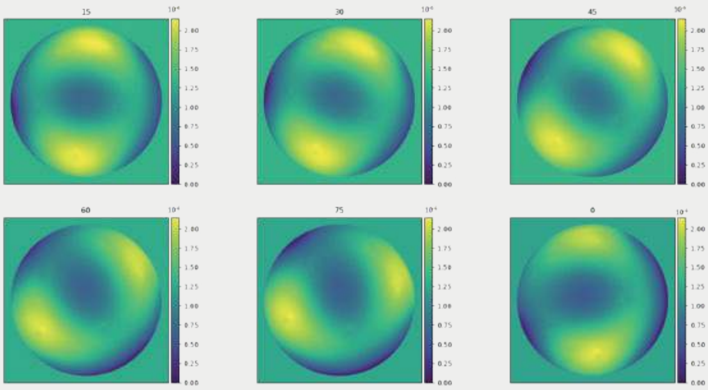

Figure 6. Multiple angles of astigmatism wavefronts, expressed in metres

Wooptix SEBI® RT1000: Applications in research and industry

SEBI® RT1000 is a highly versatile wavefront sensor that can easily adapt to various experimental settings. Its unique characteristics make it ideal to characterize both lenses and laser beams in real time and detect critical deformities.

The sensor adaptable system allows for changes in magnification and other optical adjustments making it a versatile tool with applications in different fields.

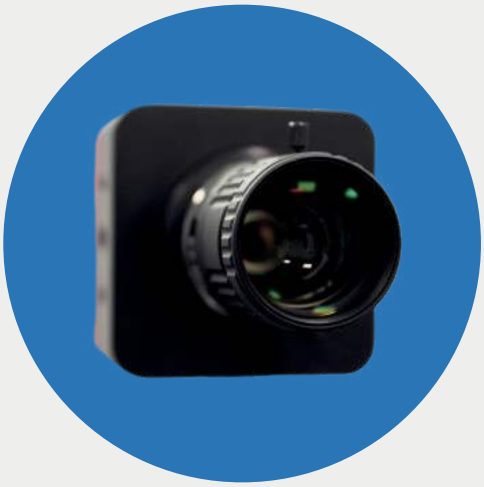

Figure 7. SEBI® RT1000

Following a comparison of the SEBI® RT1000 and a standard wavefront sensor, both instruments demonstrated comparable results under normal circumstances. However, the RT1000 exhibited enhanced sensitivity and accuracy in the Z-axis. In situations where lateral resolution was of the utmost importance, the SEBI® RT1000 proved to be the superior option. The results demonstrated that an increased lateral resolution enables the capture of greater detail in higher frequencies, beyond the capabilities of conventional microlens sensors.

When deployed in real-time scenarios, the SEBI® RT1000 is highly effective in the analysis of a diverse range of samples exhibiting behavioral variability. Potential applications include metrology, real-time laser beam and lens characterization, and microscopy.

The SEBI® RT1000 is suitable for a wide range of applications. In conventional applications it produces results comparable to those of standard wavefront sensors. Nevertheless, it can achieve the highest level of detail needed to distinguish differences in heights, and enhance the sensitivity to potential high-frequency signals.

This wavefront sensor is one of those instruments that can simultaneously detect low and high-frequency details on the same phase image.

It is the result of research that combines images captured at various propagation distances, which is an important area of investigation for the future.

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