

Puntino

Shack-Hartmann wavefront sensor for optimizing telescopes



1. Optimize telescope performance with a powerful set of tools

A finely tuned telescope is the key to obtaining deep, high-quality astronomical images.

Puntino, our Shack-Hartmann wavefront sensor specially developed for telescopes, is based on our extensive experience of its use at observatories around the world.

It gives you complete analysis of the optics, mechanics, mirror supports, mirror and dome seeing.

Based on the analysis, the software suggests corrective action to be taken, enormously simplifying maintenance work, enabling you to achieve in hours what would normally take longer.

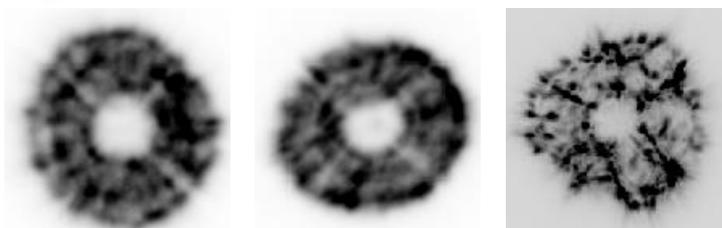
In keeping with our philosophy of providing you with a full set of tools, we also provide a CCD-based system for alignment telescopes and autocollimators.

2. Gain up to 1 magnitude by fine tuning

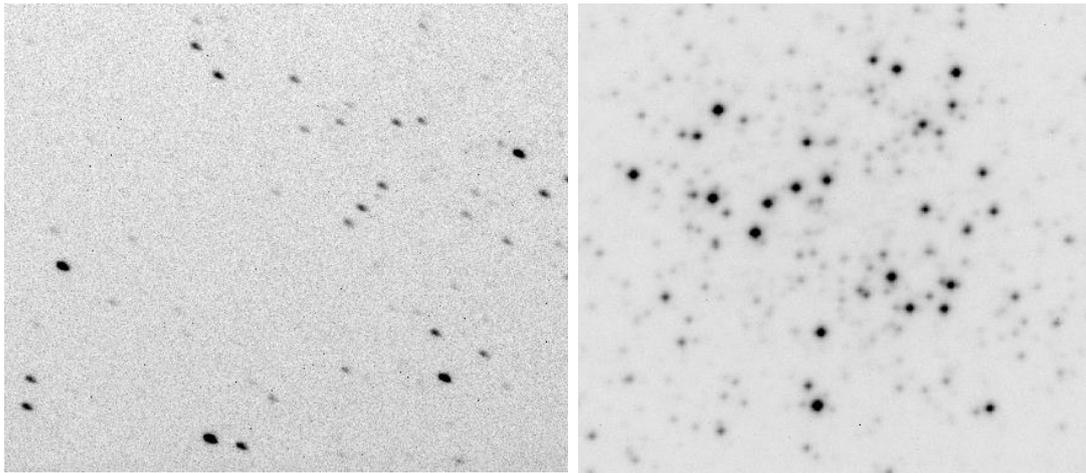
Adjusting a telescope is a delicate and time-consuming process, which, if not done frequently, can lead to images affected by aberrations. This not only results in loss of efficiency (up to 1 magnitude), but can also give rise to images that are non-regular, and hence difficult to analyze.

Moreover, if the focal plane that is being used is not correct, it will result in the image having spherical aberration, which will enlarge the image symmetrically (since it is a symmetric aberration), and it will be mistaken for the effect of seeing.

With the help of PuntinoPro, the telescope can be adjusted quickly. Some examples are shown below.



The pupil of two telescopes (taken with the finder CCD of PuntinoPro) which had astigmatism (center and left) and triangular coma (right). The two images at left are intra and extra focal, and show the elongation of the image due to astigmatism, as well as the 90-degree inclination between the two. The image on the right shows the triangular image caused by the wrong adjustment of the three fixed points supporting the primary mirror



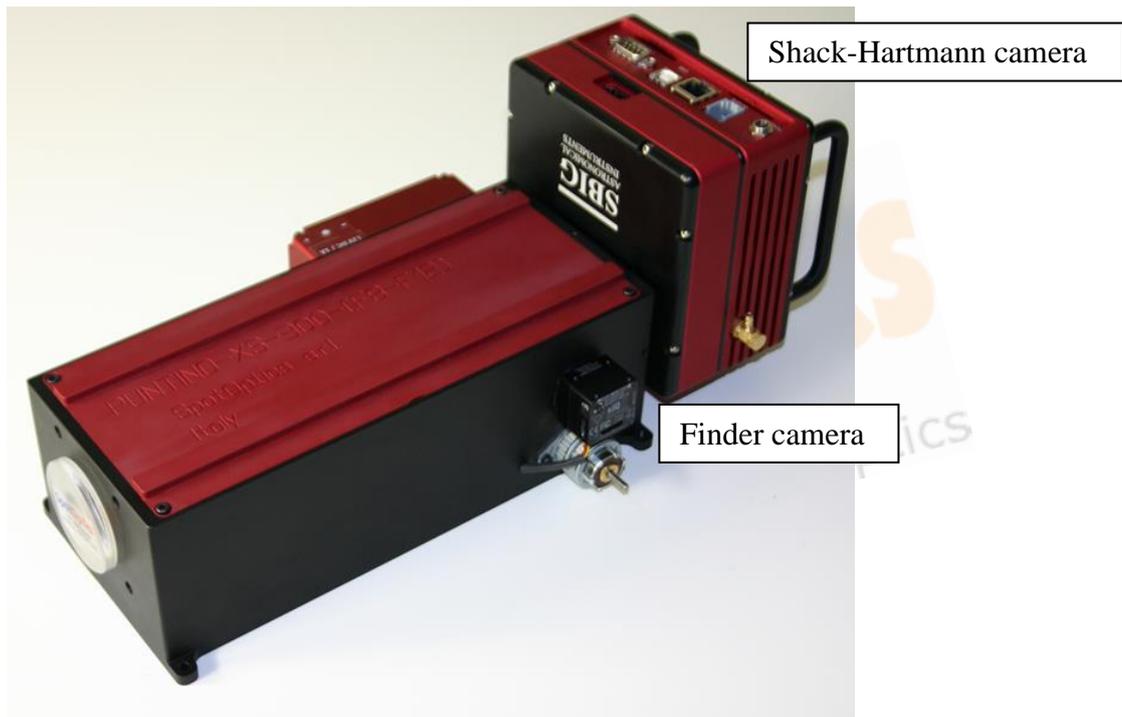
The images from a telescope that has astigmatism (left) that is slightly out of focus. Note the elongation of the images due to astigmatism. The elongation was not caused by telescope tracking errors, as the EW direction is horizontal. The picture at right is of the central part of the cluster M53, after the telescope aberrations were corrected.

SpotOptics
The software people for optics

3. PuntinoPro

Designed for the professional observatory with two cameras – one for getting Shack-Hartmann images and the other for getting the direct image – as well as remote control of the calibration light source

In a professional astronomical telescope, it is not practical to mount and dismount the sensor frequently, as it interferes with regular observations. PuntinoPro is completely automated, with a motorized remote control for the calibration system. It also comes with two cameras, and advanced hardware and software functions



4. Puntino minisensor



Designed for the small observatory

It is mounted on the telescope only when the SH test is to be done, as part of a periodic maintenance schedule.

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5. Features: overview

- Measure the aberrations of any optical system (up to 34 terms of the Zernike polynomials).
- Estimate optical quality and Strehl ratio.
- Inspect the wavefront corresponding to any aberration.
- Use the diagnostics given by the program to focus any system. The program gives the magnitude (in mm) *and* the direction for effecting the correction.
- Use the indications given by the software to align the optical system in minutes (instead of hours). Use the indications given by the software (magnitude and direction) to move the optical element for effecting the alignment. It takes the guesswork out of alignment.
- Find out the correct focal plane using the spherical aberration measured by PuntinoPro. The program again gives you the magnitude and direction in which to move the element or the focal plane.
- Use this information in a feedback loop during manufacturing.
- Use it for identifying support errors by shown by the wavefront map after mathematically subtracting the lower order aberrations.
- Identify air turbulence by inspecting the plots of the residuals.
- See *on-line* how the aberrations change during the night.
- Build/refine a sophisticated pointing model for the telescope using the indications given by PuntinoPro of the shift of image in the focal plane of the telescope for different positions in the sky.
- The program can accept temperature measurements provided by the user using a special software module. This provides an important check on the correlation of temperature with any of the aberration coefficients.

In the next sections, we give an overview of our instruments. A more detailed list of the hardware and software features of PuntinoPro can be found in the section Features of the Shack-Hartmann analysis software Sensoft Version 5.1 for PuntinoPro

6. Complete set of tools for the analysis and optimization of telescope performance

Initial setup of telescope with an alignment telescope using the CCD-based software package: Alisa

- Identification of the two axes of the telescope (ALT-AZ, or HA-DEC).
- Alignment of primary mirror axis with center of cell.
- Alignment of primary mirror axis with the axis of rotation of telescope.
- Align drive of M2 with optical axis.
- Initial alignment of primary and secondary mirrors axes.

Fine alignment and adjustment using PuntinoPro and Sensoft

- Alignment of M1 and M2 axes using the indications given by Sensoft (coma measurement).
- Identification of correct focal plane (zero spherical aberration) using the diagnostics of Sensoft.
- Optimization of support systems near zenith using the values of astigmatism, triangular coma, quadratic astigmatism and map of the mirror surface after subtraction of lower-order aberrations.
- Optimization of dome and mirror seeing using maps of the residuals over the pupil.
- Variation of aberrations with zenith distance and creation of look-up table
- Calibration of aberrations with zenith distance using the in-built star selection section.
- Optimization of support system with zenith distance using the in-built star selection section.

Use of second CCD camera for examining telescope pupil

- Examination of out-of-focus pupil obtained with the second CCD camera.
- Check of linearity of the M2 drive using the second CCD without mounting the alignment telescope.

Use of second CCD camera for examining telescope pupil

- Measurement of combined external seeing, dome and mirror seeing using the second CCD camera.

Active optics: correction of coma and defocus by moving secondary mirror

- Coma and focus can be corrected by passing the values of the movement computed by Sensoft to the control system of M2 via Ethernet or serial cable.
- Active optics: correction of aberrations of primary mirror
- Full active optics on the shape of the primary mirror using the coefficients computed by Sensoft. The values can be passed to the control system via Ethernet or serial cable.

Advanced optical analysis

- Based on the Shack-Hartmann data, the MTF of the telescope can be computed.

Simulations

Generation of Zernike wavefronts, Telescope design and diffraction analysis (MTF due to aberrations, ripple, micro ripple, seeing, telescope pointing, pixel size of CCD)



7. Sensoft: not only Zernike coefficients

Sensoft combines the full control of PuntinoPro (including the CCD cameras), as well as the Shack-Hartmann analysis. It not only gives the Zernike coefficients, but also the diagnostics for adjusting the telescope.

| Feature | Details |
|--|---|
| Designed for easy interpretation of the results | Sensoft not only gives the aberration coefficients of the wavefront in nanometers, but also the corresponding size (in arcseconds) due to the aberrated image in the focal plane, making it easier to interpret the results. |
| Detailed computations | 3 SH loops are computed automatically at every run: one for Actual Quality (only tilt and defocus removed), Real Quality (user selected Zernike aberration terms removed), and Potential Quality (first 7 Zernike terms removed). It is thus possible to have a clear idea of the current telescope quality, the potential telescope quality, and information on any single aberration. |
| Error analysis | The errors of the coefficients and probability of goodness-of-fit are computed. |
| Correcting defocus | Sensoft gives a very precise measure of the defocus, in terms of the movement of the secondary mirror. |
| Alignment: using the value of coma to correct it | Based on the telescope parameters, Sensoft gives you the movements of the secondary mirror (decentering or tilt) required for correcting coma - both magnitude and direction. |
| Measure the conic coefficient | The high dynamic range of the instrument ($\sim 100\times$ of spherical aberration) can give the conic coefficient of the (hyperbolic) primary mirror. |
| Finding the correct focal plane from the measured spherical aberration | At the Cassegrain focus, Sensoft can be used to find the correct focal plane, defined as the plane where spherical aberration is zero. Based on the telescope parameters, it gives you the magnitude and the direction by which the focal plane must be shifted to get zero spherical aberration. |
| Astigmatism, Triangular coma and Quadratic astigmatism | The presence of these aberrations indicates the presence of support errors. Using the values of these coefficients in conjunction with the surface map of the mirror, mirror supports can be optimized. |
| High-resolution map of the support imprints | The sampling of 22x22 spots on the pupil gives a high-resolution map of the mirror surface after removing the lower order Zernike terms. In conjunction with the measured astigmatism, triangular coma and quadratic astigmatism, mirror supports can be optimized. |
| Extensive graphs for ease of interpretation | Sensoft is rich in graphs: 37 in the full version. |
| Averaging to reduce noise due to air effects | The coefficients of multiple SH frames can be averaged to reduce noise due to air turbulence as well as dome seeing effects. |
| Fast computation loop | The full set of computations takes less than 2 seconds. |
| Optimization of dome and mirror seeing | A plot of the residuals over the pupil after the Shack-Hartmann analysis can be used to investigate dome and mirror seeing. The pupil image from the second CCD camera can also be used. |
| Detailed Help | An extensive Help (over 20MB), with very detailed explanations of the most basic concepts. |

8. Mounting PuntinoPro and the frequency of tests

It is desirable to check the state of the telescope every evening before starting observations. It has been designed to allow it to be mounted off-axis, so that the regular observing schedule is not disturbed. It comes equipped with a remote control for the calibration source, which enables the reference frame (for calibrating the instrumental aberrations) to be taken as frequently as required to compensate for temperature and telescope position changes during the night.

| Permanent mounting of PuntinoPro off-axis | |
|---|--|
| Using a flat-mirror | PuntinoPro can be mounted off-axis, and the light from the telescope can be directed to it by flipping in a flat-mirror (which is removed after the tests are done). This enables the test to be done every evening, before observations start. |
| As part of the guider | Using appropriate optics, PuntinoPro can be made part of the guiding unit of the telescope, and can thus be used even during the night. Since the guider is used off-axis, the off-axis (field) aberrations of the telescope need to be removed. In the case of a classical Cassegrain telescope these are coma and astigmatism, and in the case of a Ritchey-Chretien telescope, only astigmatism. These values depend on the telescope parameters, and can be input into Sensoft, which removes the effect of these aberrations. |

9. Frequency of SH tests

Ideally the tests should be done continuously throughout the night. However, if this is not possible, the tests should be done at the beginning of the night.

Frequency of acquisition of calibration reference frames

The calibration frame of PuntinoPro should be taken whenever the temperature changes by a few degrees, or when the telescope is moved by a large angular distance.

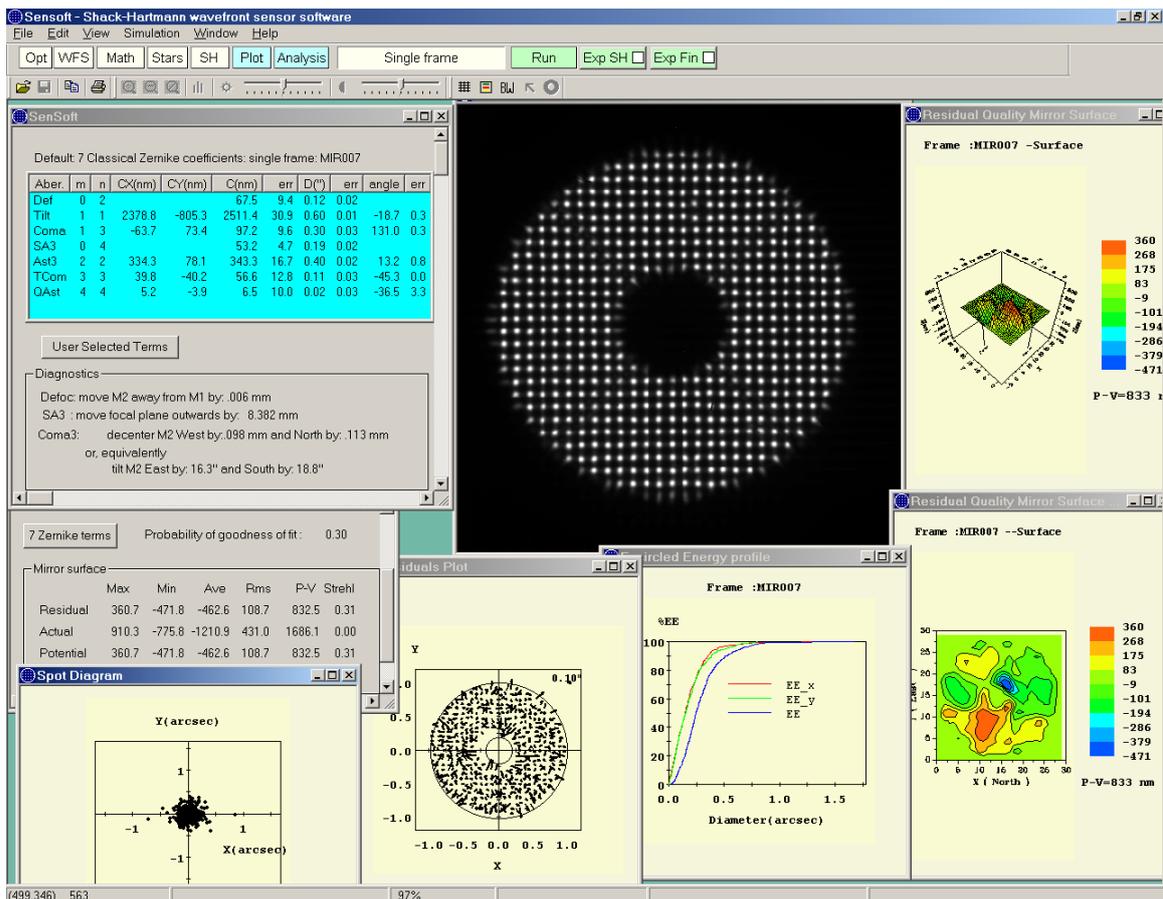
10. Sensoft: instrument control and analysis

Sensoft integrates the full control of PuntinoPro.

- Control of CCD cameras and stepper motor
- SH analysis

By specifying a few parameters when you run the program for the first time, you are set for the full night. Analysis of the Shack-Hartmann frame is again a matter of one click of the mouse.

You can get a good Shack-Hartmann frame, analyze it and get the first results in less than a minute.



The graphical user interface of Sensoft, with some of the graphs shown

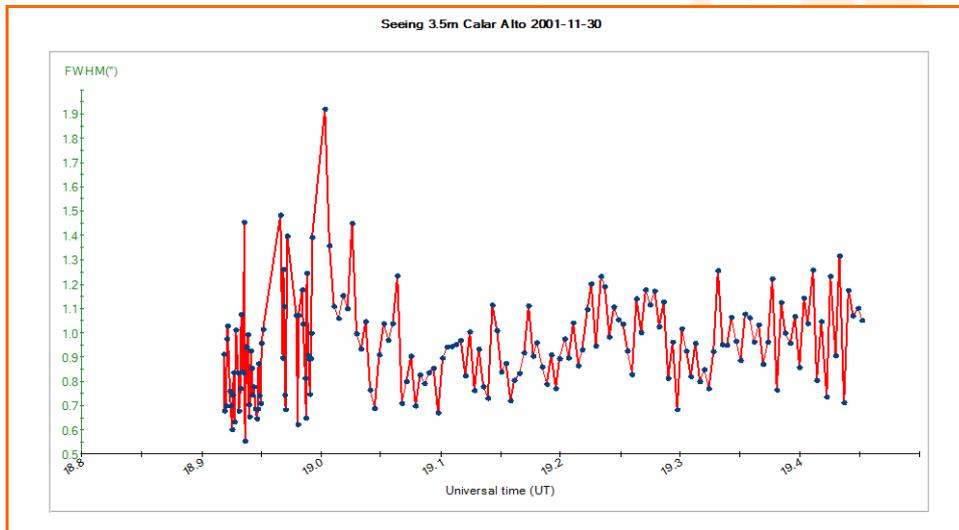
11. Summary of features of PuntinoPro

| Hardware |
|---|
| Number of spots: about 40x40 (standard). Higher number available on request. |
| High sampling over pupil for a more reliable determination of spherical aberration |
| 2 cameras (one for SH images, the other for direct images). The camera for obtaining SH images is a CCD camera and can be selected by the user (e.g. a cooled camera). The camera for direct imaging is a CMOS camera with 1280x1024 pixels of size 5.4 μ . |
| Remote control of stepper motor from PC for the calibration light source. |
| Shape of instrument: box with 4 M-6 holes on front flange for mounting. |
| Software: control and analysis |
| CCD and motor control integrated into software. |
| Coefficients of up to 34 Zernike terms (Seidel, Standard, Fringe and Annular) – user selected. |
| Wavefront (P-V, rms), Strehl Ratio. |
| Software indication for correcting measured defocus, coma and spherical aberration. |
| Advanced image analysis. |
| Intra-focal and extra-focal images recorded with second CCD. |
| Measurement accuracy of Zernike in the presence of noise (seeing dependent): $\sim 0.1''$. |
| Averaging of coefficients obtained from SH analysis to reduce effect of noise due to air effects. |
| Plots of variation of aberrations during the night. |
| Star catalog in program for calibration of aberrations with zenith distance. |
| Optional features for PuntinoPro |
| Computation of MTF, PSF and EE from Shack- Hartmann data. |
| On-line control for active optics. |
| Measurement of total seeing (external, dome and mirror) using the second camera. |
| Calibration of the linearity of the focusing drive of the secondary mirror. |
| Simulations: Generation of Zernike wavefronts, Telescope design and diffraction analysis (MTF due to aberrations, ripple, micro ripple, seeing, telescope pointing, pixel size of CCD). |
| Fast (50Hz) tip-tilt corrections. |

12. MIMMsoft: for seeing measurement

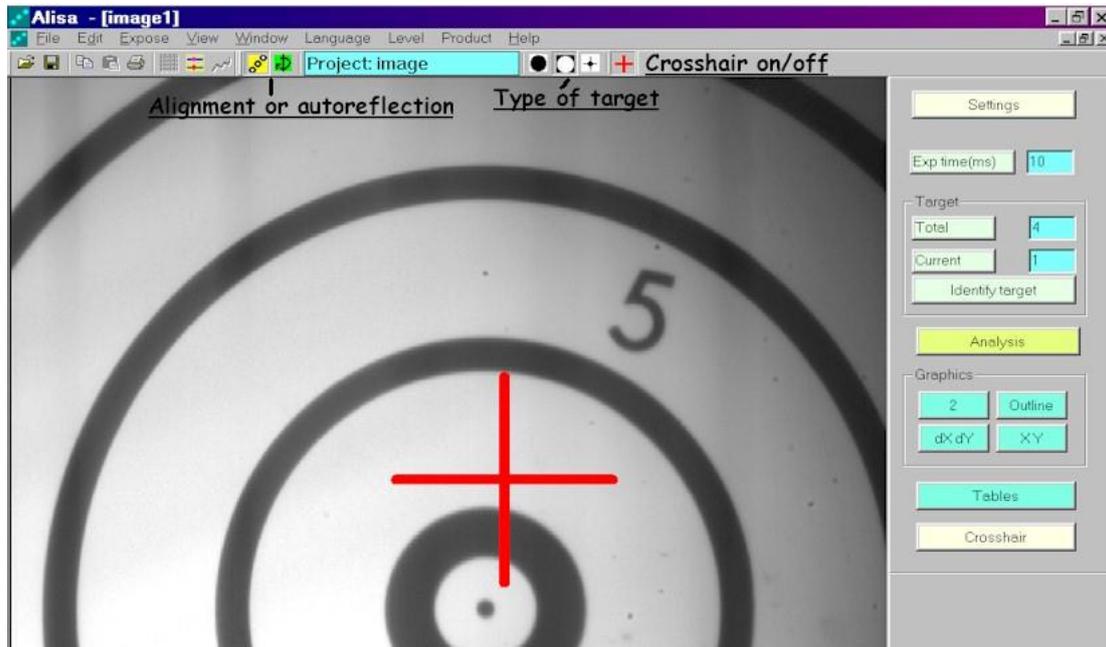
MIMMSoft is a software package for measuring astronomical seeing. Its highlights are:

- Can be used to measure seeing using a single aperture (like at the focus of a large telescope so that windshake is not a problem) or with a DIMM (dual image motion monitor)
- Can be used with the finder camera of Puntino, the Shack-Hartmann wavefront sensor made by SpotOptics s.r.l. for testing telescopes. Thus, in combination with the detailed information on the aberrations obtained from Shack-Hartmann analysis, a complete picture of the telescope performance can be obtained, which includes the effect of dome and mirror seeing
- Measures and displays, in real-time, the measured value of the FWHM (the seeing), σ (the 2D variance of the image motion), or r_0 (Fried's parameter)
- The data can be saved and retrieved and plotted at a later time
- Up to 1000 frames can be used for computing the value of r_0
- A minimum exposure time of 0.01ms can be used (with bright stars, of course), leading to a very large bandpass of 1MHz for the computation of Scintillation Index
- Automatic optimization of exposure time for precise centroiding
- MIMMsoft is a stand-alone package as well as an optional package in Sensoft



13. Alisa: software for micro-alignment

In line with our philosophy of providing you with a complete solution, we also offer the Alisa software and camera for use with an alignment telescope and autocollimator. This can be used for initial alignment and setup of the telescope, and helps reduce the tedium of alignment by substituting the eyepiece by a digital camera: the image of the target is obtained and analyzed by software.



14. Technical specifications

| | |
|--|---|
| Type of elements that can be tested | Astronomical telescopes (at Cassegrain, prime and Newtonian focus). Telescopes in the laboratory. Lenses. |
| Focal ratios covered | f/1.8 to f/300 standard. Faster focal ratios can be tested with special setup. |
| Focal length of lenslets ⁽¹⁾ | 41mm |
| Standard sampling on the pupil | About 40x40 |
| Maximum sampling | Up to 65x65 spots (camera dependent). |
| Analysis Software | Sensoft. |
| Precision of Zernike polynomials coefficients (laboratory) | $\lambda/300$. |
| Precision of Zernike polynomials coefficients (telescope) | 0.01" |
| Precision with which the wavefront is computed | $\lambda/150$ rms |
| Wavelength range | With standard camera from 0.375 up to 1.1 μ . |
| Reference source | LED. Remotely controlled. |
| Distance from flange to instrument focus | 54.8mm. |
| Height of optical axis from base | 51.5mm. |
| Camera for SH | 16-bit cooled CCD. |
| Camera for Finder | 10-bit uncooled CMOS, 1280x1024pixels, 5.4 μ pixel size or 14 or 16-bit cooled CCD. |
| Dimensions (Focal ratio dependent) | 9 (Height) x 22 (Length) x 9 (Width) cm. |
| Power requirement (stepper motor) | 12V, 1000mA |

Notes and explanations:

1. Lenslets with different diameters and focal lengths available on request.

15. About the firm

SpotOptics was founded in 1996. We offer complete solutions in the field of optics and software, covering any phase from the design of optics and software analysis to the fully developed end-user product.

We have about two decades experience in the field of optical design and software analysis and development. Our software specialization is in the development of software for image processing as well as industrial process control.

Our main product is the wavefront sensor based on the Shack-Hartmann principle. Our Shack-Hartmann wavefront sensors give the optical quality of a large sample of different optical surfaces: from the astronomical telescopes with diameters of several meters, to the DVD lenses and mobile phone with diameter of a few millimeters, to the human eye.

The use of our instruments is made very simple because of the advanced compact optical design and the degree of automation. The control software specifically developed by us allows the full control of the instrument, and our Shack-Hartmann analysis software gives you very precise indications about the quality of the optical element under test. Finally a detailed diagnostics suggests how the optical quality can be improved. All the results from the software are available in a few seconds.

Our first Shack-Hartmann sensor was developed for the test of mirrors of astronomical telescopes. Our Shack-Hartmann wavefront sensor for astronomy PuntinoPro is now operative on several telescopes in Italy, Spain, India and USA. We have been consultants for a number of observatories and firms (including Zeiss) for the alignment and quality control of telescopes. Thus PuntinoPro has been also mounted on several additional telescopes in Europe, Africa and USA.

While Puntino has been developed specially for astronomical telescopes, Optino/Opal/Lentino are Shack-Hartmann wavefront sensors designed and realized for the optical test in the laboratory and in the production environment and can test a large variety of optical elements both in transmission and reflection. Laserino is the sensor designed and realized for the test of lasers. We can test laser at practically any wavelength from UV to 10.6 μ (LWIR, CO₂).

Finally we have developed a series of sensors for testing optical elements both on-axis and off-axis. Sfera can test small lenses like mobile phone lenses, Stella can test large lenses like telecentric lenses and 5Star can test objective lenses like zoom lenses mounted on digital cameras

We have developed further products in the field of optical alignment and in the medical field.

For further details on our products, please visit: www.spot-optics.com.

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