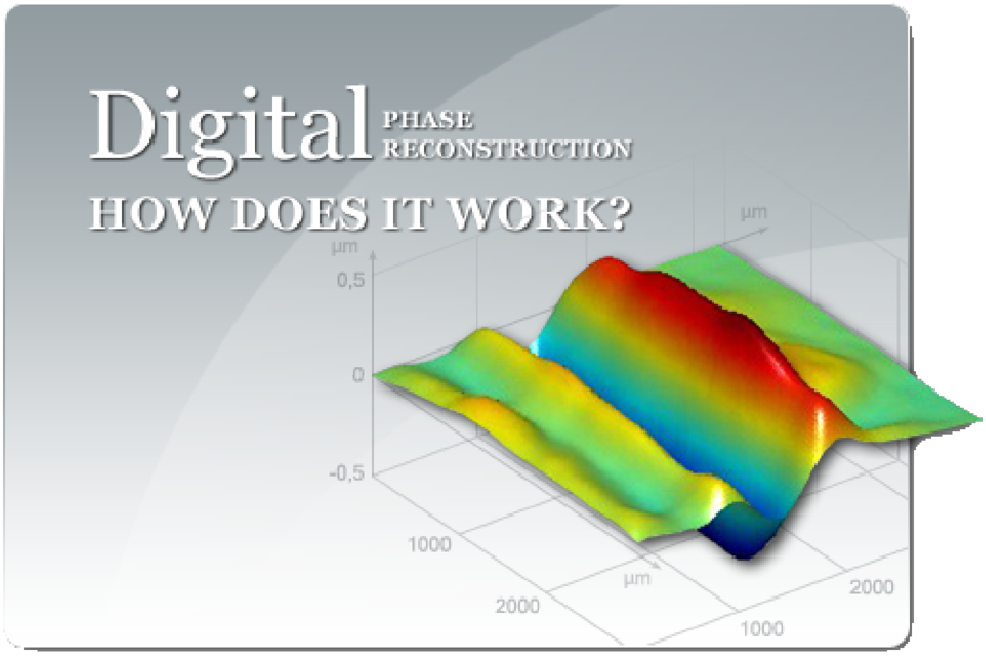
PhaseView

The easy way to view in 3D



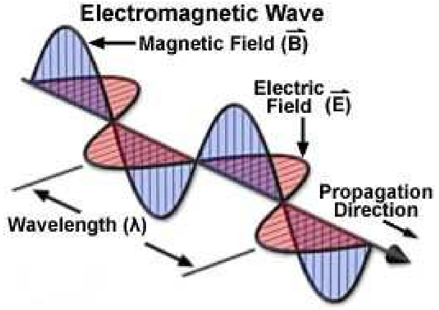
Context

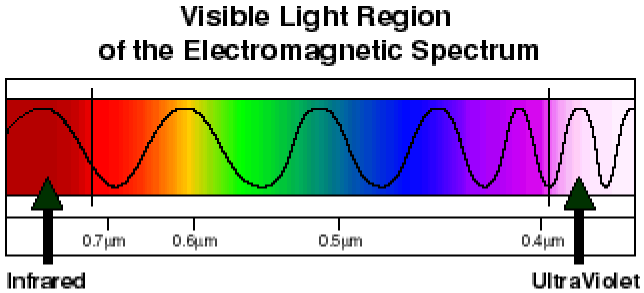
In conventional microscopic imaging of materials and life cells, only object intensity and color are imaged. However, light bears another information about the 3D structure of the object with which the light interacted: the phase. The phase of the electromagnetic illumination, reflected from an opaque sample or transmitted through a semi-transparent medium, contributes to the information already available through the observation of intensity and color. This information is the 3D shape of the object.

Digital Phase Reconstruction of PhaseView® allows to reconstruct the 3D shape of an object, and thus adds the missing dimension to the microscopic imaging, the information about spatial shape of the measured object.

Light Propagation

Visible light is one of the forms of the electromagnetic radiation, the one that fluctuates in time with the wavelengths between 300 and 800 nanometers. Its propagation is formally described by the electric vector and magnetic vector that fluctuate in directions perpendicular to each other and to the direction of the beam. These vectors satisfy a set of fundamental Maxwell partial differential equations. The Maxwell equations describe how the *variation* in the electric vector influences the *value* of the magnetic field vector, and vice versa.



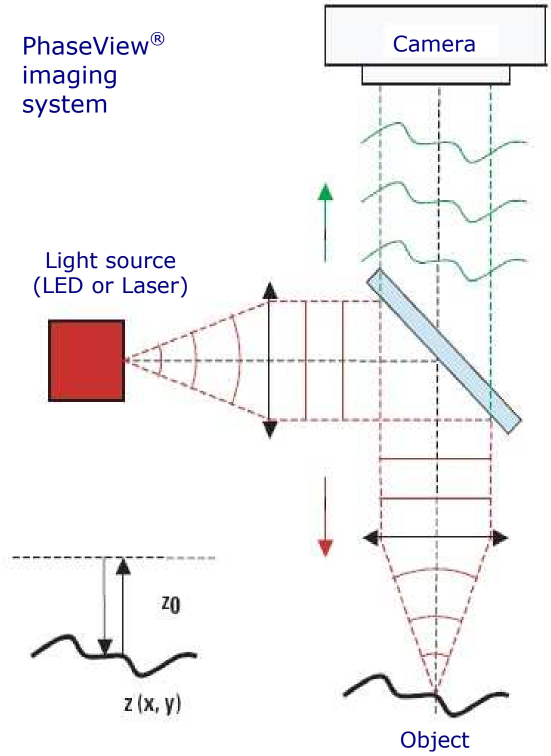


Starting from the fundamental electromagnetic equations, PhaseView® developed a numerical technology that couples the spatial variation of the electromagnetic power to the 3D shape of the illuminated object.

Digital Phase Reconstruction

The PhaseView® technology relies on efficient methods of solving systems of differential equations that govern the light energy propagation that is described by the vector quantity, the Poynting's vector.

In practice, only the real part of the average longitudinal component of the complex Poynting's vector is measured by a camera. This part is a well-known intensity. The argument of the complex amplitude of fluctuations of the electro-magnetic wave is the phase. The phase of the incident wave changes when the wave reflects from a measured sample. The 3D topography of the sample is imprinted on the reflected wave's phase as compared to the incident wave's phase. This phase difference is used to measure surface topography and its parameters like the surface roughness.



The reconstruction of the phase is possible since the variation of the energy traveling with optical waves in the 3D space is related to the phase of the wave. The conservation of the light energy during the light propagation makes it possible to develop a system of differential equations and to solve it numerically.

The analytic formula, expressing the principle of the light energy conservation, is the equation of continuity. The commonly used interpretation of the equation of continuity is incomplete and simplistic to reconstruct the phase from the intensity. PhaseView® revised the equation of continuity and developed the system of differential equations to numerically reconstruct the phase of the electromagnetic beam directly from the intensity of the beam.

Relative to existing theories of the electromagnetic wave propagation, PhaseView® developed a new theory that takes account of the *vector* nature of the electromagnetic field, as opposed to a usually assumed *scalar* field hypothesis.

Furthermore, the non-polarized (natural) light is used in real-life experiments, and assumed in the PhaseView® technology. In optics, this chaotic polarization stems from the breaks of oscillations in atoms during the period of 10^{-8} seconds. As a result, the axial symmetry of the electrical vector oscillation is a characteristic feature of the natural light.

PhaseView® solved the problem of the electromagnetic wave energy propagation and found the argument of the complex number $u(\vec{r}) = I(\vec{r})\exp[\ j\varphi(\vec{r})\ ]$ starting from observations (on a digital camera) of the averaged value $I(\vec{r}) = W\left|\left\langle \vec{S}_z \right\rangle\right|^2$ of the longitudinal component of the complex Poynting's vector $\vec{S}(\vec{r}) = \vec{e} \times \vec{h}$, $\vec{E}$ and $\vec{H}$ being the electrical and magnetic components of the vector electromagnetic field :

$$\begin{aligned} \vec{E} &= \frac{j}{k} W\ \nabla \times \vec{H} = \vec{e}\ \exp(jkz) \\ \vec{H} &= -\frac{j}{kW}\ \nabla \times \vec{E} = \vec{h}\ \exp(jkz) \quad k = \frac{2\pi}{\lambda}, W = \sqrt{\frac{\mu}{\varepsilon}} = 120\,\pi\,. \\ \vec{B} &= \mu \vec{H} \end{aligned}$$

Since the fundamental equations are differential ones, the measurement systems of PhaseView® acquire necessary amount of intensity data (a series of intensity images), feed them into a powerful differential equation solver to solve the system of equations to find the phase.

The variation of the energy traveling with optical waves is recorded with the camera moving along the axis of the optical system made of built-in projection lenses. The necessary amount of data is collected when two or more images of intensity are acquired by the camera. Therefore, the numerical nature of the PhaseView®'s technology requires only a cost-effective optical setting, comprising a light source (LED) and a camera.

Due to numerical nature of its Digital Phase Reconstruction technology, PhaseView® offers a complete digital method of phase reconstruction that relies only upon the intensity data acquisition by a camera, and a numeric reconstruction of the phase from the measured intensity data.

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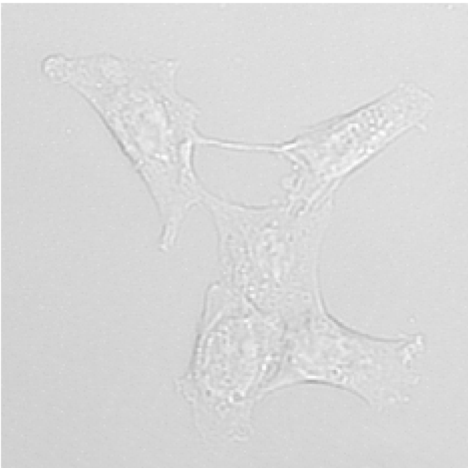
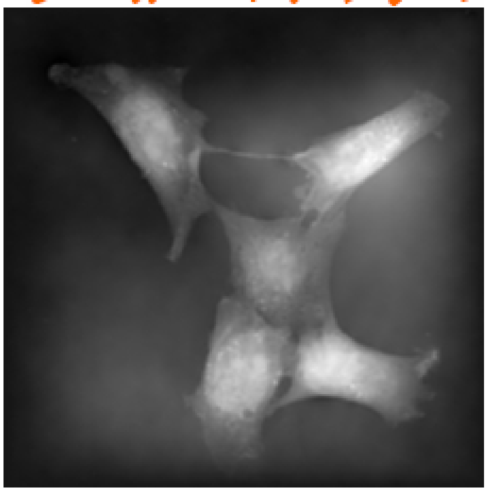
Benefits of Digital Phase Reconstruction

The technique's simplicity to set up, its low implementation cost and insensitivity to vibrations compared to established techniques makes it a very efficient procedure for routine quality control in industrial environments. Starting from the reconstructed object topography, both qualitative and quantitative types of analyses are possible.

See the invisible!



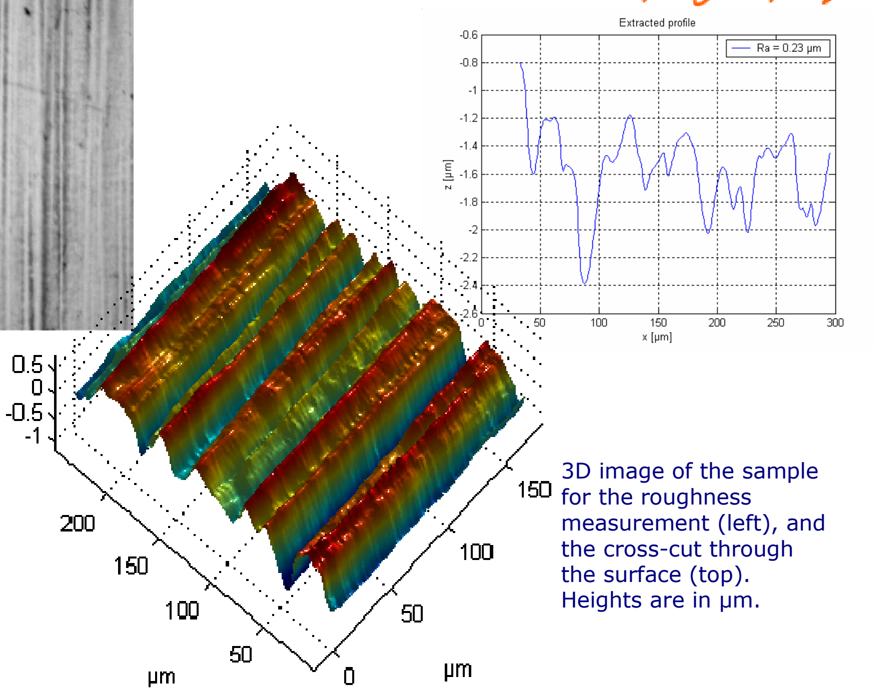
A conventional intensity image of a muscular cell, as view by a microscope



Enhanced contrast view of the cell from PhaseView® technology

Measure the 3D Topography!

Detail of surface of a metallic sample for the roughness measurement.



3D image of the sample for the roughness measurement (left), and the cross-cut through the surface (top). Heights are in µm.

Qualitative inspection is used to observe surface defects like scratches or dust particles on the surface of optical components, or to enhance contrast while observing biological samples, that are almost invisible with conventional intensity images without any fluorescent markers.

Quantitative measurement consists in characterizing objects based on their reconstructed 3D topography: measurement of the shape (step height) or measurements of statistical parameters (i.e. roughness).

Q & A's

Q: Is this technology truly quantitative?

A: The Digital Phase Reconstruction technology was certified by National French laboratories, and confronted to results from interferometric systems on industrial standards. PhaseView® products complied with international roughness standards (ISO). A certificate of compliance with standards is supplied with each PhaseView® product.

Q: What are the main parameters which influence lateral and axial resolution ?

A: The overall resolution is insensitive to exterior parameters, and there are no resolution-limiting factors inherent to the Digital Phase Reconstruction technology. The lateral resolution depends on camera pixel size and objectives. The Z-resolution depends on several parameters, including camera noise, translation stage positioning repeatability and light source stability. In the PhaseView® products, these parameters were optimized so that best performances are achieved.

Q: What are the limitations? How does PhaseView® technology compare to the other established techniques?

The limitations of the PhaseView technology are the same as with the well-known phase-shift interferometric technique, i.e. on the maximum phase step between two neighboring pixels. However, as opposed to the interferometric and digital holography techniques, the PhaseView® technology is far less sensitive to vibrations, it does not involve alignment of optical components, and it does not require a coherent illumination.

Unlike confocal microscopy, PhaseView® is fast as there is no need for acquiring a stack of intensity images. Compared to local correlation contrast-based 3D imaging techniques, Digital Phase Reconstruction allows measuring specular samples. PhaseView® offers greater resolution at no hardware cost in comparison to Schack-Hartmann technique. Easy-to-use, fast and accurate are unrivaled benefits as PhaseView® technology is digital with no need of complex optical components.

Q: What are the differences with 3D reconstruction from Z stack used in others technologies?

A: In shape reconstruction from a stack of 2D images acquired as a camera moves in the axial (Z) direction, the height of a point on the surface is determined when the maximum optical signal output is observed. The precision with which the height is determined depends on the scanning step of the camera in the axial direction.

The procedure is repeated enough times to cover all the measured surface, so the data acquisition is time consuming, but the data processing is (comparatively to the PhaseView® case) straightforward. Unmeasured points and outliers are common problems of this technique, due to inaccurate location, by the maximum-contrast or wavelet techniques, of the height corresponding to the maximum optical signal. The additional interpolation and is usually carried out to fill in the unmeasured points, that lowers the overall precision.

In PhaseView® technology, data processing plays a crucial role: indeed, once the variation of the incident energy is registered by the camera through a simple acquisition process, the 3D profile is reconstructed by the Digital Phase Reconstruction software. Therefore, the cost-effectiveness of the PhaseView® technology is explained by its underlying numerical nature, ability to faithfully reconstruct the whole surface without interpolation, and a minimum use of optical components.

Q: Do I need to be an expert in Digital Phase Reconstruction for using PhaseView® products?

A: PhaseView® measurement systems are fully automated certified equipment providing data according to international standards. A simple button push allows fast data acquisition, topography measurement and analysis implemented by the built-in software. With no need of complex setup or calibration procedures, in less than 5 seconds a user obtains 3D topography images of material samples in the nanometer resolution range. So there is no need of heavy trained operator: in a couple of minutes training, any operator can fully understand data acquisition and processing steps and can generate a measurement report.

Q: Are PhaseView® products calibrated before installation on the user's site?

A: To fine-tune the optical system parameters such as the magnification and offset the camera drift, a thorough calibration procedure is performed prior to installation of the PhaseView® systems on the user's site. Calibration management is provided to ensure proper metrological performances during the product's lifetime. A calibration tool is supplied with the products, so the operator can easily check if calibration is correct.