

OPTICAL SENSOR**Technical Field**

The invention relates to the field of optical displacement sensors for measuring the displacement of a measurement object relative to the sensor. The invention may be used in the context of a displacement sensor for measuring the displacement of the measurement object relative to the optical sensor, for measuring the 2D profile of the measurement object, or for measuring the 3D shape of the measurement object.

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Background

Prior art coaxial confocal chromatic 3D sensors analyse light reflected from the surface of a measurement object with a spectrograph that contains components that disperse the wavelengths laterally to different angular directions, e.g. gratings or prisms.

The prisms produce large image distortion (a so-called "smile effect") and are difficult to position and tune. In other cases where a diffraction grating may be used, but the different order modes create difficulties, such as ghost images.

Moreover, the linearity of the range of positions over which the height of the surface of the measurement object can be measured is dictated by the properties of the lenses and must be corrected by software.

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Summary of the Invention

According to a first aspect of the invention, an optical sensor for measuring the displacement of a measurement object relative to the sensor is provided. The optical sensor is configured to:

- project polychromatic measurement light within a measurement region;
- using an objective lens component, focus measurement light reflected from the intersection of a surface of the measurement object and the measurement region at a first focus point such that the wavelength of the focused measurement light at the first focus point depends on the distance of the intersection of the surface of the measurement object and the measurement region from the objective lens component, wherein the first focus point is located within a first aperture;

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- using a second lens component, focus measurement light received from the first aperture onto the surface of a diffractive or non-specular reflective component at different distances from the second lens component depending on the wavelength of the received measurement light;
- 5 • image measurement light diffracted or reflected from the diffractive or non-specular reflective component onto an active surface of a photodetector; and
- sense the intensity of light received at different positions on the active surface of the photodetector.
- 10 The surface of the diffractive or non-specular reflective component may be parallel to and coincident with the optical axis of the second lens component.

- The magnitude of lateral chromatic dispersion of the light passing through the objective lens component may be less than 10% of the magnitude of longitudinal chromatic dispersion of
- 15 light passing through the objective lens component. The magnitude of lateral chromatic dispersion of the light passing through the second lens component may be less than 10% of the magnitude of longitudinal chromatic dispersion of light passing through the second lens component.

- 20 The optical axis of the objective lens component may be aligned with the optical axis of the second lens component.

- The first aperture may be configured to allow measurement light focused at the first focus point to pass while at least partially blocking measurement light that is not in focus at the first
- 25 focus point.

The first aperture may be aligned with the optical axis of the objective lens component.

- The first aperture may be aligned with the optical axis of the second lens component.
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The diffractive or non-specular reflective component may be a diffraction grating. The diffraction grating may be a blazed diffraction grating. The groove density and/or blaze angle of the diffraction grating may vary over at least one direction across the surface of the diffraction grating.

The diffractive or non-specular reflective component may be a non-specular reflector.

5 The optical sensor may further comprise a sensor lens component configured to focus light diffracted or reflected from different points on the surface of the diffractive or non-specular reflective component onto corresponding points on the active surface of the photodetector.

10 The optical axis of the sensor lens component may be perpendicular to or within 5, 10, or 15 degrees of perpendicular to the active surface of the photodetector.

15 The optical sensor may be configured to project the polychromatic measurement light within the measurement region using a light source, and the light source may be configured to project measurement light within the measurement region via the objective lens component such that measurement light is focused by the objective lens component within the measurement region at different distances from the objective lens component depending on the wavelength of the measurement light.

20 The optical sensor may be configured to project the polychromatic measurement light within the measurement region using a light source, and the light source may be configured such that measurement light from the light source passes through a second aperture before being received by the objective lens component. The second aperture may be positioned at the same distance from the objective lens component as the first aperture.

25 The second aperture may be configured to allow measurement light focused at a second focus point, located within the second aperture, to pass while at least partially blocking measurement light that is not in focus at the second focus point.

30 The optical sensor may be configured such that measurement light, received from the light source before being projected onto the measurement object, passes through a third lens component before passing through the second aperture, and the third lens component may be configured to focus measurement light at the second focus point.

The third lens component may cause longitudinal chromatic dispersion of light passing through the third lens component.

The optical sensor may further comprise a specular reflector for allowing measurement light received from the light source before being projected onto the measurement object to reach the objective lens component and allowing reflected measurement light reflected from the surface of the measurement object to reach the first aperture from the objective lens component.

The specular reflector may be positioned to allow measurement light, received from the light source before being projected onto the measurement object, to reach the objective lens components and to reflect light reflected from the surface of the measurement object towards the first aperture from the objective lens component.

The specular reflector may be positioned such that measurement light, received from the light source before being projected onto the measurement object, reaches the objective lens component without passing through the first aperture.

The optical sensor may comprise a specular reflector for allowing measurement light from the light source to reach the second lens component and allowing reflected measurement light reflected from the surface of the measurement object to reach the diffractive or non-specular reflective component from the second lens component.

The specular reflector may be positioned to reflect measurement light received from the light source towards the second lens components and to allow measurement light reflected from the surface of the measurement object to reach the photodetector from the second lens component.

The light source may comprise an array of LEDs, and the intensity of measurement light emitted by each LED or group of LEDs may be varied independently.

The light source may comprise a second diffractive component, and the light source may be configured to project measurement light onto the second diffractive component such that measurement light is diffracted from the second diffractive component towards the measurement object.

The array of LEDs may be configured such that the wavelength of light emitted by the LEDs of the array of LEDs varies over a first direction.

5 The light source may comprise a light source lens component configured to focus light emitted by the array of LEDs on the surface of the second diffractive component.

10 The wavelengths of light emitted by the LEDs of the array of LEDs, the magnification of the light source lens, and the longitudinal chromatic dispersion of the third lens component may be configured such that light emitted by the LEDs of the array of LEDs is in focus at the second focus point.

15 The wavelengths of light emitted by the LEDs of the array of LEDs, the magnification of the light source lens, and the longitudinal chromatic dispersion of the second lens component may be configured such that light emitted by the LEDs of the array of LEDs is in focus at the first focus point.

The LEDs of the array of LEDs may be configured to emit polychromatic light.

20 According to a second aspect of the invention, a method for determining a two-dimensional profile of a measurement object using the optical sensor of any preceding claim is provided. The method comprises determining the two-dimensional profile of the measurement object based on the locations on the active surface of the photodetector of the optical sensor at which light is sensed with the highest intensity.

25 The method may further comprise repeatedly determining the two-dimensional profile of the measurement object at different positions on the measurement object and generating output data comprising the determined two-dimensional profiles and the displacements between the determined two-dimensional profiles.

30 The method may further comprise processing the determined two-dimensional profiles of the measurement object and displacements between the determined two-dimensional profiles to generate the three-dimensional model of the measurement object.

Brief Description of the Drawings

Figure 1 depicts an optical sensor according to a first embodiment of the invention.

5 Figure 2 depicts a measurement region of an optical sensor according to the present invention.

Figure 3 depicts the intensity peak of light projected onto a component of the optical sensor of the present invention.

10 Figure 4 depicts an optical sensor according to a second embodiment of the invention.

Figure 5 is a flow diagram depicting a method of measuring the displacement and/or 2D profile of a measurement object, and optionally determining the 3D profile of the measurement object using the sensor of the present invention.

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Detailed Description of the Invention

The invention relates to optical sensors for displacement, 2D profile and 3D shape sensing. The invention exploits optics with longitudinal chromatic dispersion (i.e. axial chromatic
20 aberration) to sense the position from which light is reflected from the surface of a measurement object. The chromatic dispersion caused by the optics of the present invention is preferably only longitudinal chromatic dispersion. An optical sensor according to the present invention does not require the use of lateral chromatic dispersion (i.e. transverse chromatic aberration), thus reducing (or eliminating) the negative effects of lateral chromatic
25 dispersion described above on the dynamic range and measurement accuracy. Furthermore, the invention may make use of a novel light source, which uses an array of LEDs that can be independently adjusted in wavelength and/or power in order to produce uniform illumination of the measurement object.

30 In particular, the invention deviates from the prior art by the way in which measurement light received from the surface of the measurement object is spectrally analysed. Instead of using gratings or prisms to laterally disperse the reflected measurement light, the sensor of the present invention disperses reflected measurement light longitudinally onto the surface of a diffractive or non-specular reflective (i.e. scattering) component, such that each wavelength of

reflected measurement light has its own longitudinal position on the diffractive or non-specular reflective component. Thus, in the present invention, the spectral analysis of the reflected light does not use any components that are intended to laterally disperse the reflected measurement light for the purpose of dispersing the spectrum of reflected measurement light. The purpose of the diffractive or non-specular reflective element is to enable the longitudinally dispersed spectrum of the reflected measurement light to be imaged by a photodetector at a smaller average angle of incidence than if the photodetector were positioned directly in the place of the diffractive or non-specular reflective element. Any lateral dispersion of the spectrum caused by the diffractive or non-specular reflective component is incidental. As a result, spectral analysis of the reflected measurement light simpler than in the prior art and the negatives associated with prior art prism or grating based optics, discussed in the background section above, are avoided. Furthermore, with the sensor of the present invention it is possible to make the measurement of the distance linear on the camera surface irrespective of the nonlinearity of the longitudinal chromatic dispersion of the measurement lens when the longitudinal chromatic dispersion caused by objective lens 103 is similar to that of second lens 105, e.g. when then objective lens and second lens cause symmetric longitudinal chromatic dispersion of light.

In general, the optical sensor of the present invention projects polychromatic measurement light within a measurement region. When in use, this polychromatic measurement light is projected onto the surface of a measurement object, i.e. the object for which displacement, profile or shape is to be measured, at the intersection of the surface of the measurement object and the measurement region.

Measurement light is reflected from the surface of the measurement object, i.e. from the measurement region, and focused by an objective lens component which causes longitudinal chromatic dispersion of light passing through. Thus, measurement light reflected from the intersection of the surface of the measurement object and the measurement region is focused at a first focus point such that light focused at the first focus point depends on the wavelength of the light and the position from which it was reflected.

The first focus point is located within an aperture, referred to as a "first" aperture to distinguish it from other apertures that may be part of the optical sensor. The aperture allows light focused at the first focus point to pass but at least partially blocks light focused outside of

the aperture from passing. Thus, the intensity of reflected measurement light passing through the aperture depends on its wavelength and the position from which the measurement light was reflected.

- 5 Reflected measurement light that passes through the aperture is focused onto a diffractive or non-specular reflective component, e.g. by a second lens component, which also causes longitudinal chromatic dispersion of light passing through it. Therefore, the position at which light passing through the aperture is focused on the diffractive or non-specular reflective component depends on its wavelength, which corresponds to the position from which
- 10 measurement light was reflected from the surface of the measurement object. Thus, the position(s) on the surface of the diffractive or non-specular reflective component at which measurement light is in focus, i.e. has the highest intensity, corresponds to the position of the surface of the measurement object relative to the sensor.
- 15 Measurement light reflected or diffracted from the diffractive or non-specular reflective component is imaged onto the active surface of a photodetector, which is configured to sense the intensity of light received at different position on the active surface of the photodetector. In this context, "imaged" means that an image of the light reflected (i.e. scattered) or diffracted from the diffractive or non-specular reflective component is formed on the active surface of
- 20 the photodetector. In other words, light reflected or diffracted from different points on the surface of the diffractive or non-specular reflective component is focused at corresponding points on the active surface of the photodetector. In this way, the displacement or 2D profile of the measurement object can be sensed. By scanning the measurement object through the measurement region, the 3D shape of the measurement object can be constructed based on
- 25 the changing 2D profile.

- Figure 1 depicts a first embodiment of the invention as described above. The optical sensor 100 projects polychromatic measurement light from light source 101 within a measurement region 102. The measurement region 102 is a region in which polychromatic measurement
- 30 light is focused by an objective lens component 103, as described in more detail below. The measurement region 102 is aligned with the optical axis of the objective lens component 103. The measurement region 102 extends primarily along two axes: a first measurement region axis is parallel to the optical axis of the objective lens component 103 and a second measurement region axis is perpendicular to the optical axis of the objective lens component

103. The wavelength of light that is in focus within the measurement region varies along the first measurement region axis due to longitudinal chromatic dispersion of measurement light caused by the objective lens component 103.

- 5 The measurement region is defined as the region of space in which light of different wavelengths is focused by the objective lens component 103 and which is eventually imaged onto the active surface of the photodetector 109. In an ideal system, the measurement region has zero thickness, i.e. it would be a two-dimensional region on the plane defined by the first measurement region axis and second measurement region axis. However, in practice, the
- 10 measurement region has a non-zero thickness in a third measurement region axis, which is perpendicular to the first measurement region axis and the second measurement region axis. In Figure 1, the first measurement region axis is parallel to the Z-axis, the second measurement region axis is parallel to the X-axis, and the third measurement region axis is parallel to the Y-axis. It is preferable to keep the thickness of the measurement region in the
- 15 third measurement region axis as small as possible in order to produce a sharper intensity peak on the photodetector 109.

- The light source 101 includes an area light source 110, light source lens component 111, and diffractive component 112. In some embodiments, area light source 110 may be, for example,
- 20 an array of LEDs or other light emitting components. The wavelength of each LED or other light emitting component is chosen such that the wavelength of light emitted by the light emitting components varies over a first light source axis. The orientation of the first light source axis corresponds to the first measurement region axis, in that the orientation and direction of the first light source axis is the same as the first measurement region axis taking
- 25 into account changes in orientation and direction caused by reflection, diffraction and/or focusing of measurement light between the area light source 110 and the measurement region 102. In Figure 1, the first light source axis is parallel to the Y-axis. Figure 1 shows exemplary paths of light of two different wavelengths, λ_1 and λ_2 , which are the end-points of the wavelength range making up the measurement region 102. λ_1 is indicated by a dotted line and λ_2 by a dashed line in Figure 1. Dash-dotted lines indicate the bounds of paths travelled by all wavelengths of light measurement light that are projected into the
- 30 measurement region 102.

The area light source 110 may include a diffuser component on top of the light emitting components in order to smooth the output and optical spectrum emitted from the area light source 110. Alternatively, the light source lens component 111 discussed below may be arranged such that the light source array is out of focus on the surface of the diffractive component 112 such that light emitted by each discrete light emitting component overlaps with light from neighbouring components on the surface of diffractive component 112.

In alternative embodiments, instead of emitting light with varying wavelength across the first light source axis, area light source 110 may emit white light across the first light source axis. Thus, according to an alternative embodiment of the invention to that depicted in Figure 1, the light source may emit a line of white light across the first light source axis. In this context, "white light" means a continuous spectrum of electromagnetic radiation over the range of wavelengths that are in focus in the measurement region. In these embodiments, the light source and optical sensor in general may be otherwise configured as described above and below. Since the second lens 105 can focus only one or a small range of wavelengths from each position of the diffractive component 112 to the aperture 104, the use of wide wavelength band light in all position of the light source 110 is less efficient, but simplifies the construction and technical requirements of the light source 110.

The light source lens component 111 focuses light emitted by the array of LEDs on the surface of the diffractive component 112. The light source lens component 111 may be a singlet lens, complex lens or combination of lenses and other optical components. The light source lens component 111 does not need to cause chromatic dispersion of light passing through it. The light source lens component 111 focuses light emitted by the light emitting components of area light source 110 onto the surface of diffractive component 112 such that the wavelength of light incident at each point on the surface of the diffractive component 112 varies in the same manner as the variation in wavelength of light emitted by the array of LEDs, although the direction of change from low to high wavelength is reversed on the surface of the diffractive component due to the flipping of the image of the array of LEDs by light source lens component 111. The lens 111 may also cause chromatic dispersion of light passing through it. The lens component 111 images the positions of the light source 110 to corresponding positions to the diffractive component 112. Since the second lens 105 has longitudinal chromatic aberration that causes different wavelengths to be in focus at different positions on the surface of the diffractive component 112 it is beneficial to position a light

emitting component at such a position in the light source 110 that the wavelength of the LED corresponds to the wavelength of the corresponding focus point of the second lens 105 on the surface of the diffractive component 112.

- 5 The diffractive component 112 may be a diffraction grating, preferably a blazed diffraction grating. A blazed diffraction grating is advantageous since blazed diffraction gratings are optimised to achieve maximum grating efficiency at a given diffraction order, i.e. more of the incident light is diffracted at the selected order. Since a blazed diffraction grating is optimised for a single or narrow wavelength band, the groove density and blaze angle may vary over
- 10 the first direction in which the wavelength of incident light varies in order to optimize the grating efficiency for the specific wavelength incident at each point. Alternatively, the power of the light emitting components may be varied to account for varying grating efficiencies at different wavelengths.
- 15 The diffractive component 112 diffracts the measurement light focused onto its surface by the light source lens component 111 towards second lens component 105, e.g. via a reflector 106 as shown in Figure 1. In other words, diffractive component 112 is configured such that at least one diffraction mode of measurement light focused onto its surface is diffracted at an angle that lies within the angle of acceptance of the second lens component 105. Diffractive
- 20 component 112 is aligned with the optical axis of the second lens component 105 and objective lens component 103. By varying the intensity of light emitted from light emitting components of the area light source 110, the intensity of light in focus in the measurement region can be varied. This enables uniform illumination within the measurement region, which improves the accuracy of displacement/profile measurements.
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- The reflector 106 allows both the diffractive component 112 and diffractive or non-specular reflective component 107 to all be aligned with the optical axis of the second lens component 105. In Figure 1, reflector 106 is depicted at a 45-degree angle to the surface of the diffractive component 112 and at a 45-degree angle to the shared optical axis of the second lens
- 30 component 105. It will be appreciated that other angles may be used. Furthermore, reflector 106 may alternatively be a beam splitter/combiner across the full width of the second lens 105, rather than a pure specular reflector positioned across half of the width, as shown in Figure 1.

Since second lens component 105 causes longitudinal chromatic dispersion of light passing through it, second lens component 105 focuses measurement light diffracted from different locations on diffractive component 112 at a first focus point fp1 depending on the wavelength of light. Thus, light is focused at the first focus point fp1 by selecting appropriate wavelengths
5 of light emitted by the area light source 110 across the first light source axis, the magnification of the light source lens 111, and the magnitude of longitudinal chromatic dispersion of the second lens component 105.

The first focus point fp1 is located within an aperture 104. This aperture 104 may be referred
10 to as a "first" aperture to distinguish it from other apertures that may be part of the optical sensor in other embodiments of the invention. The aperture 104 allows light focused at the first focus point fp1 to pass but at least partially blocks light focused outside of the aperture 104 from passing.

15 The aperture 104 may be a slit, a pinhole, a series of pinholes arranged in a line, a series of small slits arranged in a line, or any other combination of slits and pinholes arranged in a line. When the optical sensor 100 is used to measure a 2D profile of a measurement object, the aperture 104 is a slit or a combination of slits and/or pinholes arranged in a line. If the optical sensor is simply used to measure displacement of a single point on the surface of a
20 measurement object, the aperture 104 may be a single pinhole. The aperture may be an opening in an opaque material or, in some cases, an optical fibre. For example, a pinhole aperture may be provided by an optical fibre, and a series of pinholes may be provided by a series of optical fibres. Where the aperture is a slit, it may have a width of 20µm and a length of 12mm, for example, where width is measurement parallel to the Y-axis and length is
25 measured parallel to the X-axis.

Measurement light passing through aperture 104 is received by the objective lens component 103, which focuses the measurement light received from aperture 104 into the measurement region 102. The objective lens component 103 also causes longitudinal chromatic dispersion
30 of light passing through it, therefore measurement light received from light source 101 via the second lens component 105 and in focus at focus point fp1, which is "white" light, i.e. a combination of the wavelengths of light diffracted from the diffractive component 112, is dispersed along the optical axis of the objective lens component 103. As such, different

wavelengths of measurement light are in focus at different distances from the objective lens component 103.

When in use, this polychromatic measurement light focused by the objective lens component
5 103 is projected onto the surface of a measurement object 130 at the intersection of the
surface of the measurement object 130 and the measurement region 102. The range of
distances over which the measurement light is dispersed and focused by the objective lens
component 103 is determined entirely by the properties of the objective lens component 103.
If the lenses 103 and 105 are identical, each wavelength is in focus at the same distance from
10 the lens 103 in the measurement region as the distance from the lens 105 on the diffractive
component 107. This gives linear distance measurement response irrespective of the
possible nonlinearity of the longitudinal wavelength dispersion of the lenses.

Measurement light is reflected from the surface the measurement object 130 back towards
15 the objective lens component 103 and focused by the objective lens component 103. Since
the objective lens component causes longitudinal chromatic dispersion of light passing
through it, the distance at which reflected measurement light is focused from the objective
lens component 103 on the light source/sensor side of the objective lens component 103
depends on its wavelength and the distance from the objective lens component 103 on the
20 measurement objection 130 side of the objective lens component 103 from where it is
reflected. Thus, focused measurement light that is reflected from the intersection of the
surface of the measurement object 130 and the measurement region 102 is focused at the
first focus point fp1 and passes through the aperture 104.

25 Reflected measurement light that passes through the aperture 104 is focused onto a
diffractive or non-specular reflective component 107 by the second lens component 105,
which, as discussed above, also causes longitudinal chromatic dispersion of light passing
through it. Therefore, the position at which light passing through the aperture 104 is focused
on the diffractive or non-specular reflective component 107 depends on its wavelength, which
30 corresponds to the distance from the objective lens component 103 from which the
measurement light was reflected. Thus, the position(s) on the surface of the diffractive or non-
specular reflective component 107 at which measurement light is in focus, i.e. where the
measurement light has the highest intensity, corresponds to the distance from the objective
lens component 103 from which measurement light was reflected.

The function of the diffractive or non-specular reflective component 107 is to enable the focused and spectrally dispersed measurement light to be imaged by the photodetector 109 at a smaller angle of incidence, i.e. such that the average angle of incidence of measurement light on the photodetector is lower than the average angle of incidence of measurement light on the diffractive or non-specular reflective component. In general, the sensitivity of photodetectors decreases as the angle of incidence of light on the photodetector increases. Thus, imaging at a lower angle, as described above, increases the sensitivity of the photodetector and allows for a more sensitive measurement of the intensity of light given the same output power of the light source 101. Preferably, the photodetector is positioned such that the optical axis of the sensor lens component is perpendicular to or within 5, 10, or 15 degrees of perpendicular to the active surface of the photodetector. Greater angles may also be used, although the performance will not be as high as when the photodetector is positioned at a low or zero angle. The main point is that the diffractive or non-specular reflective component 107 should produce at least scattered or diffracted light that could be sensed by the photodetector.

Preferably, the diffractive or non-specular reflective component 107 is a diffraction grating. A diffraction grating, in particular a blazed diffraction grating, results in a larger proportion of the light incident on the diffractive or non-specular reflective component 107 being redirected within the angle of acceptance of the sensor lens component 108 compared to a non-specular reflective component. In Figure 1 a reflective diffractive or non-specular reflective component 107 is depicted, but a transmissive diffractive component may alternatively be used.

Measurement light reflected or diffracted from the diffractive or non-specular reflective component 107 is focused onto the active surface of a photodetector 109, which is configured to sense the intensity of light received at different position on the active surface of the photodetector 109. In this way, the displacement or 2D profile of the measurement object can be sensed. By scanning the measurement object through the measurement region, the 3D shape of the measurement object can be constructed based on the changing 2D profile.

While the sensor 100 of Figure 1 has been described in combination with the light source 101, which projects measurement light into the measurement region 102 via the objective

lens component 103, the measurement optics may be used with other types and configurations of light sources. The use of the light source 101 in the manner described above is a preferred option which leads to increased accuracy.

5 Figure 2 depicts the measurement region 102 in more detail. As shown in Figure 2, measurement region 102 is aligned with the optical axis 202 of the objective lens component 103 (not shown). Where the measurement region 102 intersects the surface of measurement object 130, a bright line 201a-c is visible. For the sake of providing a clear explanation of the invention, visible measurement light is discussed here. However, the measurement light is
10 only visible if some or all of the measurement light is in the visible range of electromagnetic radiation. In practice, other parts of the electromagnetic spectrum may be used instead of or in addition to the visible spectrum. The colour (i.e. more generally wavelength) of the line depends on the distance of the surface of the measurement object from the objective lens component 103 measured along the optical axis 202, i.e. parallel to the Z-axis. This distance
15 may therefore be called the "Z-distance" and its position within the measurement region may be referred to as the "Z-position". Measurement light reflected from section 201a has a first wavelength, measurement light reflected from section 201b has a second wavelength, and measurement light reflected from section 201c, which has the same Z-position as section 201a, has the first wavelength. The wavelength of measurement light reflected from the
20 sloped sections between section 201a and 201b, and between 201b and 201c, varies continuously between the first wavelength and the second wavelength depending on the Z-position from which it is reflected.

Figure 3 shows the light intensity distribution on the surface of the diffractive or non-specular reflective component 107, where measurement light reflected from the surface of
25 measurement object 130 as shown in Figure 2 is focused onto its surface by the second lens component 105. The light is focused to a Line 301 that corresponds to the shape of the surface of the measurement object 130 within the measurement region 102 from which measurement light is reflected. The shape of the surface of the measurement object is
30 present as an intensity peak, e.g. visible as a bright line, on the surface of the diffractive or non-specular reflective component 107. The same intensity peak is imaged and measured by the photodetector 109 as described above in order to sense the shape of the surface of the measurement object.

Figure 4 shows a second embodiment of the invention. Components labelled with similar reference numerals in Figure 4 and Figure 1, e.g. 101 and 401, have the same function unless otherwise explained below. Sensor 400 operates according to the same principle as sensor 100, but the light source 401 and reflector 406 of sensor 400 are positioned differently
5 to the light source 101 and reflector 106 of sensor 100. Furthermore, sensor 400 uses a third lens component 413 and second aperture 414 when projecting measurement light into the measurement region 402, rather than the second lens component 105 and aperture 104 in sensor 100. Reflector 406 may alternatively be a beam splitter/combiner across the full width of the objective lens component 403, rather than a pure specular reflector positioned across
10 half of the width, as shown in Figure 4.

Light source 401 is configured in the same way as light source 101 discussed above with respect to Figure 1. Light emitted from the light source 401, i.e. diffracted from diffractive component 412 is diffracted towards a third lens component 413. Third lens component
15 causes longitudinal chromatic dispersion of light passing through it and therefore functions in the same manner as described above with respect to second lens component 105 of sensor 100. However, unlike second lens component 105, which focuses measurement light from the light source 101 at the first focus point fp1 located within the first aperture 104 (through which measurement light reflected from the surface of the measurement object also passes), third
20 lens component 413 focuses measurement light received from the light source 401 at a second focus point fp2, which is located within a second aperture 414. Light passing through the second aperture 414 is incident on a reflector 406, which reflects measurement light from the aperture 414 towards the objective lens component 403. Objective lens component 403 focuses measurement light within the measurement region 402 as described above with
25 respect to Figure 1. Other than as described above, sensor 400 operates in the same way as sensor 100. Sensor 400 reduces direct optical crosstalk from the light source 401 to photodetector 409 compared with sensor 100, but is more complex and requires additional components.

Figure 5 is a flow diagram depicting a method for determining the position, two-dimensional profile or three-dimensional shape of a measurement object. At step 501, measurement light
30 is projected into a measurement region of a sensor according to the present invention, as described above. At step 502, measurement light reflected from the surface of a measurement object, which intersects the measurement region, is sensed by the sensor. At step 503, the displacement of a point on the surface of the measurement object or the two-

dimensional profile of the surface of the measurement object is determined based on the locations on the active surface of the photodetector of the optical sensor at which light is sensed with the highest intensity, as discussed with respect to Figure 3 above.

- 5 When determining the three-dimensional shape of the measurement object, step 503 always includes determining the two-dimensional profile of the measurement object. At a further, optional, step 504, the sensor is moved relative to the measurement object, or vice versa, by a known displacement, and at step 505 the two-dimensional profile of the measurement object is measured again at the new position. At step 506, two or more two-dimensional
- 10 profiles are combined using the known displacement between the two-dimensional profiles, e.g. by interpolating the two-dimensional profiles.

The term “lens” or “lens component” should generally be understood to refer to an optical device that focuses or disperses light by means of refraction, and may be a singlet lens, a

15 compound lens, or a combination of singlet and/or compound lenses with other optical components.

The term “measurement light” refers to light emitted from a light source for the purpose of measuring the displacement/2D profile of a measurement object.

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The term “polychromatic” means electromagnetic radiation made up of many different wavelengths of radiation, and includes electromagnetic radiation with continuous ranges of wavelengths of radiation as well as multiple discrete, i.e. separate, ranges of wavelengths.

Claims

1. An optical sensor for measuring the displacement of a measurement object relative to the sensor, the optical sensor configured to:
 - 5 project polychromatic measurement light within a measurement region;
using an objective lens component, focus measurement light reflected from the intersection of a surface of the measurement object and the measurement region at a first focus point such that the wavelength of the focused measurement light at the first focus point depends on the distance of the intersection of the surface of the
 - 10 measurement object and the measurement region from the objective lens component, wherein the first focus point is located within a first aperture;
using a second lens component, focus measurement light received from the first aperture onto the surface of a diffractive or non-specular reflective component at different distances from the second lens component depending on the wavelength of
 - 15 the received measurement light;
image measurement light diffracted or reflected from the diffractive or non-specular reflective component onto an active surface of a photodetector; and
sense the intensity of light received at different positions on the active surface of the photodetector.
- 20 2. The optical sensor of claim 1, wherein the surface of the diffractive or non-specular reflective component is parallel to and coincident with the optical axis of the second lens component.
- 25 3. The optical sensor of claim 1 or 2, wherein the magnitude of lateral chromatic dispersion of the light passing through the objective lens component is less than 10% of the magnitude of longitudinal chromatic dispersion of light passing through the objective lens component, and/or wherein the magnitude of lateral chromatic dispersion of the light passing through the second lens component is less than 10% of the magnitude of
- 30 longitudinal chromatic dispersion of light passing through the second lens component.
4. The optical sensor of any preceding claim, wherein the optical axis of the objective lens component is aligned with the optical axis of the second lens component.

5. The optical sensor of any preceding claim, wherein the first aperture is configured to allow measurement light focused at the first focus point to pass while at least partially blocking measurement light that is not in focus at the first focus point.
- 5 6. The optical sensor of claim 5, wherein the first aperture is aligned with the optical axis of the objective lens component.
7. The optical sensor of claim 5 or 6, wherein the first aperture is aligned with the optical axis of the second lens component.
- 10 8. The optical sensor of any preceding claim, wherein the diffractive or non-specular reflective component is a diffraction grating.
9. The optical sensor of claim 8, wherein the diffraction grating is a blazed diffraction grating.
- 15 10. The optical sensor of claim 9, wherein the groove density and/or blaze angle of the diffraction grating varies over at least one direction across the surface of the diffraction grating.
- 20 11. The optical sensor of any of claims 1 to 7, wherein the diffractive or non-specular reflective component is a non-specular reflector.
12. The optical sensor of any preceding claim, wherein the optical sensor further comprises a sensor lens component configured to focus light diffracted or reflected from different points on the surface of the diffractive or non-specular reflective component onto corresponding points on the active surface of the photodetector.
- 25 13. The optical sensor of claim 12, wherein the optical axis of the sensor lens component is perpendicular to or within 5, 10, or 15 degrees of perpendicular to the active surface of the photodetector.
- 30 14. The optical sensor of any preceding claim, wherein the optical sensor is configured to project the polychromatic measurement light within the measurement region using a

light source, and wherein the light source is configured to project measurement light within the measurement region via the objective lens component such that measurement light is focused by the objective lens component within the measurement region at different distances from the objective lens component depending on the wavelength of the measurement light.

15. The optical sensor of any of claims 1 to 14, wherein the optical sensor is configured to project the polychromatic measurement light within the measurement region using a light source, and wherein the light source is configured such that measurement light from the light source passes through a second aperture before being received by the objective lens component, wherein the second aperture is positioned at the same distance from the objective lens component as the first aperture.
16. The optical sensor of claim 15, wherein the second aperture is configured to allow measurement light focused at a second focus point, located within the second aperture, to pass while at least partially blocking measurement light that is not in focus at the second focus point.
17. The optical sensor of claim 16, wherein the optical sensor is configured such that measurement light, received from the light source before being projected onto the measurement object, passes through a third lens component before passing through the second aperture, and wherein the third lens component is configured to focus measurement light at the second focus point.
18. The optical sensor of claim 17, wherein the third lens component causes longitudinal chromatic dispersion of light passing through the third lens component.
19. The optical sensor of any of claims 14 to 18, wherein the optical sensor further comprises a specular reflector for allowing measurement light received from the light source before being projected onto the measurement object to reach the objective lens component and allowing reflected measurement light reflected from the surface of the measurement object to reach the first aperture from the objective lens component.

20. The optical sensor of claim 19, wherein the specular reflector is positioned to allow measurement light, received from the light source before being projected onto the measurement object, to reach the objective lens components and to reflect light reflected from the surface of the measurement object towards the first aperture from the objective lens component.
21. The optical sensor of claim 20, wherein the specular reflector is positioned such that measurement light, received from the light source before being projected onto the measurement object, reaches the objective lens component without passing through the first aperture.
22. The optical sensor of claim 14, wherein the optical sensor further comprises a specular reflector for allowing measurement light from the light source to reach the second lens component and allowing reflected measurement light reflected from the surface of the measurement object to reach the diffractive or non-specular reflective component from the second lens component.
23. The optical sensor of claim 22, wherein the specular reflector is positioned to reflect measurement light received from the light source towards the second lens components and to allow measurement light reflected from the surface of the measurement object to reach the photodetector from the second lens component.
24. The optical sensor of any preceding claim, wherein the light source comprises an array of LEDs, wherein the intensity of measurement light emitted by each LED or group of LEDs can be varied independently.
25. The optical sensor of claim 24, wherein the light source comprises a second diffractive component, and wherein the light source is configured to:
project measurement light onto the second diffractive component such that measurement light is diffracted from the second diffractive component towards the measurement object.

26. The optical sensor of claim 25, wherein the array of LEDs is configured such that the wavelength of light emitted by the LEDs of the array of LEDs varies over a first direction.
- 5 27. The optical sensor of claim 26, light source comprises a light source lens component configured to focus light emitted by the array of LEDs on the surface of the second diffractive component.
- 10 28. The optical sensor of claim 27 and any of claims 17 to 21, wherein the wavelengths of light emitted by the LEDs of the array of LEDs, the magnification of the light source lens, and the longitudinal chromatic dispersion of the third lens component are configured such that light emitted by the LEDs of the array of LEDs is in focus at the second focus point.
- 15 29. The optical sensor of claim 27 and any of claims 22 to 23, wherein the wavelengths of light emitted by the LEDs of the array of LEDs, the magnification of the light source lens, and the longitudinal chromatic dispersion of the second lens component are configured such that light emitted by the LEDs of the array of LEDs is in focus at the first focus point.
- 20 30. The optical sensor of claim 24 or 25, wherein the LEDs of the array of LEDs are configured to emit polychromatic light.
- 25 31. A method for determining a two-dimensional profile of a measurement object using the optical sensor of any preceding claim, the method comprising:
determining the two-dimensional profile of the measurement object based on the locations on the active surface of the photodetector of the optical sensor at which light is sensed with the highest intensity.
- 30 32. The method of claim 31, wherein the method further comprises:
repeatedly determining the two-dimensional profile of the measurement object at different positions on the measurement object and generating output data comprising

the determined two-dimensional profiles and the displacements between the determined two-dimensional profiles.

33. The method of claim 32, wherein the method further comprises:
- 5 processing the determined two-dimensional profiles of the measurement object and displacements between the determined two-dimensional profiles to generate the three-dimensional model of the measurement object.