becomes difficult with larger numbers of field positions to arrange a corresponding number of cameras so densely that the measurement light can enter the corresponding cameras from the desired direction.

From WO 2016/180525 A1 (corresponding to US 2018/0136079 A), an apparatus for measuring the MTF is known in which more cameras can be arranged than is the case with the conventional arrangement by means of a special beam folding.

However, even with this method, the MTF cannot be measured for all field points. This is particularly troublesome if the optical system to be measured has a variable focal length and the MTF is to be measured for different focal lengths. Since the individual images of the line crosses are created at different locations when the focal length is changed, the cameras must be realigned each time the focal length is changed. This is time-consuming and therefore not economical for the rapid measurement of optical systems manufactured in large quantities, e.g. machine-made optics of smartphone cameras.

Other apparatuses for measuring an optical property are known from TW M579270 U, TW M583048 U, TW M579270 U and CN 206638403 U.

SUMMARY OF THE INVENTION

Embodiments of the present invention seek to provide an apparatus and a method for measuring an optical property of an optical system, in which the measurement can be carried out at as many different field points as possible with a minimum of equipment.

According to a first aspect of the present invention, there is provided an apparatus for measuring an optical property of an optical system comprising an object to be imaged having a plurality of structures arranged in a plane and separated from each other. The apparatus further comprises a two-dimensional image sensor, a collecting optics with a focal length f, the image sensor having a distance a from the collecting optics with $0.9 \cdot f \leq a \leq 1.1 \cdot f$, and a holder for the optical system. The holder is arranged so that the optical system is located in the beam path between the object and the collecting optics. The image sensor and the collecting optics

are configured such a way that all structures can be imaged by the optical system and the collecting optics onto the image sensor simultaneously.

The claimed invention is based on the idea that, at least in the case of optical systems with a long focal length and a correspondingly small *field* of *view* (FOV), the entire object and thus several structures separated from one another can be imaged simultaneously on the image sensor via the optical system and the collecting optics. The large and high-resolution image sensors required for this - ideally with more than 10 megapixels - are now available at reasonable cost. Due to the generally larger etendue, the collecting optics are also more complex than with the camera lenses used to date. However, since only one image sensor and one collecting optics have to be provided and preferably arranged axially centered, the design and manufacturing effort for the apparatus according to the claimed invention is nevertheless significantly lower than for conventional apparatuses in which a large number of cameras are arranged in a dome-like manner above the optical system to be measured.

The object can be an illuminated reticle, as is known in the prior art. The structures are usually line patterns or single or double crosshairs.

It is particularly advantageous if the holder is arranged in the diverging beam path. The optical system to be measured can then have a variable focal length and, in particular, be designed as a zoom lens. Whereas in conventional apparatuses the images of the structures generally migrate completely or partially out of the image fields of the individual cameras when the focal length of the optical system to be measured is changed, in the apparatus according to the claimed invention the images can always be captured completely by the image sensor when the focal length is changed. Thus, no adjustments or readjustments have to be made if the focal length of the optical system are changed. This means that the apparatus can also be used to check the imaging properties as part of the quality control of zoom lenses intended for use in devices such as smartphones or webcams.

In another embodiment, a collimator is arranged in the light path between the object and the holder. In this case, the optical system to be measured is not in a diverging beam path,

length f of the collecting optics, leading to the condition $0.9 \cdot f \leq a \leq 1.1 \cdot f$. In some embodiments the deviation is a maximum of 5%, in other embodiments no deviation is allowed.

According to a second aspect of the present invention, there is provided a method for measuring an optical property of an optical system, which comprises the following steps:

Providing a two-dimensional image sensor, a collecting optics having a focal length f, the image sensor having a distance a from the collecting optics with $0.9 \cdot f \leq a \leq 1.1 \cdot f$, and an object having a plurality of structures arranged in a plane and separated from each other;

Insertion of the optical system to be measured into the beam path between the object and the collecting optics,

Simultaneous imaging of the object within the field of view of the specimen and the collecting optics onto the image sensor using the optical system and the collecting optics;

Evaluation of an image of the object formed on the image sensor to determine the optical property.

The considerations and advantages explained above in connection with the apparatus according to the claimed invention apply accordingly to the method.

In one embodiment, the optical system has a variable focal length. The optical properties of the optical system are measured for at least two different focal lengths.

In another embodiment, the optical system is afocal. In this case, a collimator is arranged in the light path between the object and the optical system. The object can be moved along an optical axis of the apparatus between successive measurements of the same optical system or between measurements of different optical systems.

The method according to the claimed invention can be used to measure at least one optical property selected from the group consisting of: distortion, image field curvature, field of view

and edge light fall-off. Since the method according to the claimed invention uses a large image sensor to be able to image an object in the entire field of view of the specimen, a high measurement point density is obtained. As a result, the aforementioned optical properties of the specimen can be measured with high precision and in higher orders. For example, it is possible to determine a high-order distortion polynomial, which was only possible to a limited extent with the known measuring apparatuses. In addition, the large image sensor allows structures to be imaged that extend across the entire image field, e.g. solid lines. This enables new approaches to evaluation, which is advantageous for measuring the field of view, among other things.

SHORT DESCRIPTION OF THE DRAWINGS

In the following, embodiments of the invention are explained in more detail with reference to the drawings. In these show:

Figure 1	a schematic meridional section through a measuring apparatus according to the prior art;
Figure 2	a schematic meridional section through a measuring apparatus according to a first embodiment;
Figure 3	a top view of the reticle used as object in the embodiment according to figure 2;
Figure 4	the apparatus shown in figure 3 with additionally drawn rays and a feeding device for similar optical systems to be measured;
Figures 5a and 5b	meridional sections through the apparatus shown in Figure 2 during the measurement of a zoom lens in different displacement positions of the zoom lens;
Figure 6	a schematic meridional section through a measuring apparatus according to a second embodiment for measuring an afocal optical system;

PATENT CLAIMS

1. An apparatus for measuring an optical property of an optical system, comprising:

   an object to be imaged having a plurality of structures arranged in a plane and separated from each other,

   a two-dimensional image sensor,

   a collecting optics having a focal length f, the image sensor having a distance a from the collecting optics with $0.9 \cdot f \leq a \leq 1.1 \cdot f$,

   a holder for the optical system, which is arranged such that the optical system is located in the beam path between the object and the collecting optics,

   wherein

   the image sensor and the collecting optics are configured such that all structures can be imaged by the optical system and the collecting optics onto the image sensor simultaneously.

2. The apparatus according to claim 1, wherein the object is an illuminated reticle.

3. The apparatus according to claim 1 or 2, wherein the structures are crosshairs.

4. The apparatus according to any one of the preceding claims, wherein the holder is arranged in the diverging beam path.

5. The apparatus according to any one of claims 1 to 3, wherein a collimator is arranged in the light path between the object and the holder.

6. The apparatus according to claim 5, wherein the collimator is a conoscopic lens.

7. The apparatus according to claim 5 or 6, wherein the object is movable along an optical axis of the apparatus to vary the distance between the collimator and the object.

8. The apparatus according to any one of the preceding claims, wherein the image sensor is movable along an optical axis of the apparatus.

9. A method of measuring an optical property of an optical system, comprising the following steps:

Providing a two-dimensional image sensor, a collecting optics having a focal length f, the image sensor having a distance a from the collecting optics with $0.9 \cdot f \leq a \leq 1.1 \cdot f$, and an object;

Inserting the optical system to be measured into the beam path between the object and the collecting optics,

Simultaneously imaging the object within the field of view (FOV) of the specimen and the collecting optics onto the image sensor using the optical system and the collecting optics;

Evaluating an image of the object formed on the image sensor to determine the optical property.

10. The method according to claim 9, wherein the optical system has a variable focal length, and in that the optical properties of the optical system are measured for at least two different focal lengths.

11. The method according to claim 9, wherein the optical system is afocal, and in that a collimator is disposed in the light path between the object and the optical system.

12. The method according to any one of claims 9 to 11, wherein at least one optical property selected from the group consisting of: distortion, image field curvature, field of view and edge light fall-off.