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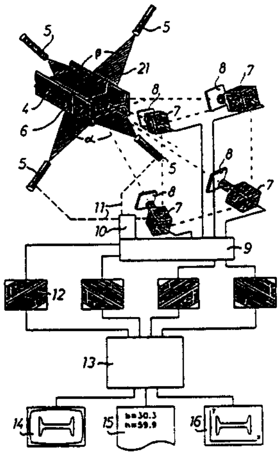
Mit internationalem Recherchenbericht.

(54) Title: PROCESS AND DEVICE FOR THE OPTO-ELECTRONIC MEASUREMENT OF OBJECTS

(54) Bezeichnung: VERFAHREN UND ANORDNUNG ZUR OPTOELEKTRONISCHEN VERMESSUNG VON GEGENSTÄNDEN

(57) Abstract

In a process for the opto-electronic measurement of the shape of objects, the object (4) to be examined is illuminated by laser light sources (5), the beam of which is widened by an optical system (not shown) in a plane so that a bright line (6) is formed on the object (4) by each laser light source (5), whereby the lines generally overlap partially. Each line (6) is detected by a semiconductor camera (7) in front of which is placed a filter (8) which is transparent only to the light emitted by the relevant laser (5). The laser light sources (5) are connected via control lines (11) to a control unit (10) which is coupled to an assessment unit (9). The assessment unit (9) comprises a computer to which the digitised video signals from the camera (7) are taken. (12) is a unit for processing the signals of the individual cameras (7) to the polygonal sections taken by each camera, (13) is a unit to combine the individual polygonal traces to form the outline of the object, (14) is a monitor to display the measured object, (15) is a printer to print out the dimensions of the object and (16) is a plotter for the graphic display of the object. In order to approximate or adapt the image size of the line of light (6) to the size of the sensor component of the semiconductor camera (7), the image scale is changed or varied or the size of the measuring field of the camera (7) concerned is altered dependently upon the size of the line of light (6) generated on the object (4) or matched thereto.



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A Process and Arrangement for the Optoelectronic Measuring of Objects

The invention relates to a process for the optoelectronic measuring of the shape, in particular the cross sectional shape, of objects, e.g. workpieces, or for calibrating optoelectronic measuring systems, wherein at least one light strip is projected from at least one light source, preferably a laser light source, onto the object to be measured and/or the calibration body (light section process), and the light strips are recorded by preferably the same number of video cameras, preferably CCD solid-state cameras, as there are light strips, and are imaged on the sensor elements of the cameras, and the camera signals are fed to an evaluation unit comprising a computer for the purpose of evaluating the image and calculating the dimensions of the object, or for determining the basic data and parameters needed for calibration. In addition, the invention relates to an arrangement for implementing this process.

The image processing systems used in such processes and arrangements have certain disadvantages specifically as regards their limited resolution, which limits the maximum achievable accuracy. Customary systems can resolve an image into, for example, 512 x 512 image points. If objects of various size are measured by means of a measuring arrangement using the light section process, small objects will naturally produce a small image on the available sensor element, i.e. the available measuring field will not be fully utilized, and the accuracy of the evaluation will suffer; small objects use up only part of the measuring field and are therefore resolved into fewer than 512 x 512 image points, and as a result the relative measuring accuracy is reduced.

The purpose of the invention is to achieve maximum image processing accuracy using measuring processes and arrangements which operate according to the light section method.

According to the invention, a process of the type mentioned at the beginning is designed in such a way that in order to approximate or match the size of the image or of the respective light strip(s) to the size of the respective sensor element, the imaging scale is modified or varied or the size of the measuring field of the respective camera is varied as a function of the size of the light strips generated on the object and/or calibration body or is adapted to the size of these strips.

An arrangement for optoelectronically measuring the shape, in particular the cross sectional shape of objects, e.g. workpieces, or for calibrating optoelectronic measuring devices, wherein at least one light strip is projected from at least one light source, preferably a laser light source, onto the object to be measured and/or the calibration body (light section process), and wherein the light strips are recorded by preferably the same number of video cameras, preferably CCD solid-state cameras, as there are light strips, and are imaged on the sensor elements of the cameras, and wherein the cameras are connected to an evaluation unit comprising a computer for the purpose of evaluating the image and calculating the dimensions of the object, or for determining the basic data and parameters needed for calibration, is characterized in the manner according to the invention in that devices are provided for modifying or varying the imaging scale of the light strip(s) and by means of these devices the image size of the light strip(s) can be varied and in particular can be adapted to the size of the respective sensor element, or devices are provided for modifying the measuring field size of the cameras and for adapting the size of the measuring field to the light strips which are to be measured on the objects or on areas of the objects and/or on the calibration bodies.

In the process and arrangement according to the invention, while the size of the sensor element in the camera remains unchanged, the evaluation of small objects or small light strips can be considerably improved by generating larger images of the light strips on the sensor element of the camera, however in such a way that all the light strips needed for the purpose of evaluation are imaged jointly or simultaneously. Whether one or more light strips from the calibration body and/or from the object are imaged on the sensor element depends on the type of evaluation process selected. If the images of the light strips are larger than the sensor element, it is of course also possible to select a smaller imaging scale and thus to adapt the image size of the light strips to the size of the sensor element. The same also applies to the light strips generated on the calibration body; these strips are needed so that the evaluation unit can judge the dimensions of the objects undergoing measurement; for this purpose, calibration bodies are measured and the measurement data thus obtained are used to evaluate the measured objects. It should also be noted that it is possible to project light strips simultaneously onto the calibration bodies and onto the objects to be measured and then to evaluate them. The process or arrangement according to the invention thus permits optimal use to be made of the resolving power of the image processing system which is used in the process or arrangement according to the invention.

In a preferred embodiment of the invention, the imaging scale of the light strip(s) imaged on the sensor element or the measuring field size can be modified by fitting the video cameras with ZOOM devices which can be adjusted, possibly by means of a motor drive, and/or by fitting the video cameras with lenses of different focal lengths and/or by varying the distance, possibly by means of a motor drive, between the video cameras and the object to be measured or the calibration body. These are simple ways of modifying the size of the images of the light strips; these devices can be operated manually or automatically via the evaluation unit.

It is preferable when, for calibration purposes, at least one calibration body of a given size is measured and the data obtained from the imaging of at least this one calibration body on the sensor element are then stored in the evaluation unit and are used to evaluate the data obtained from measuring an object. In the process and arrangement according to the invention the measurements of the light sections imaged on the sensor element are used in the evaluation unit to determine the enlargement or reduction scale chosen for imaging the respective light strip on the object and/or calibration body and these data are also taken into account when evaluating the camera signals. The devices used to adjust the imaging size or the imaging scale or the measuring field size can be controlled by the evaluation unit, namely by comparing the data from the calibration body with the data from the object to be measured or as a function of size of the images of the light strips on the sensor element. This permits the creation of an almost fully automatic measuring process having optimum accuracy characteristics.

In a preferred embodiment of the invention, provision is made for at least one light section projected onto a calibration body or a calibration mark to be imaged on the sensor element; and the size of the image of at least the one light section is adapted to the size of the sensor element; and the light strips generated on the calibration body or at the calibration marks are measured and the imaging scale or the measuring field size are determined; and the data and parameters relating to the size of the light strips and the imaging scale are stored in the evaluation unit; and when measuring at least one light strip generated on an object, the size of the image of at least the one light strip is adapted to the size of the sensor element; and by using the same imaging scale or an imaging scale deviating therefrom in a known or given manner, the object is measured using this imaging scale; and with the aid of the imaging parameters determined during the measuring and calibration steps, the dimensions of the object are calculated.

In addition, in the process and arrangement according to the invention the evaluation unit comprises a comparator for comparing the data and parameters obtained from at least one measured calibration body with the data and parameters supplied to the evaluation unit in the course of measuring an object; and the evaluation unit is connected to the devices for modifying the image scale or the measuring field size and feeds to them a control signal, based on the results of the data comparison, for the purpose of adjusting the imaging scale or the measuring field size.

The invention will be described in more detail in the following on the basis of drawings. Fig. 1 shows in diagrammatic form the structure of an arrangement according to the invention. Fig. 2 depicts the principle behind the measurement of an object or a calibration body. Figs. 3a, 3b, 3c depict various arrangements for modifying the imaging scale and Figs. 4a, b, c and d depict the measurement of calibration bodies.

Fig. 1 illustrates the principle of the measuring process. The object 4 to be examined is illuminated by a number of light sources 5, in the present case by four laser light sources 5, which may emit light of different wavelength. The light beam from the laser 5 is spread into a plane, by means of an optical system which is not depicted here, so that a bright outline or a bright strip 6 is projected onto the object being measured. Each laser 5 projects a bright strip 6 and these usually partially overlap on the object. Each light plane created by a laser 5 is advantageously oriented at right angles to the longitudinal axis of the object (angle ß); the light planes of the individual lasers are oriented in such a way that they lie as far as possible in one and the same plane, so that the strips projected by the individual lasers are as far as possible superimposed one on the other, or lie in a defined plane intersecting the object, in order right from the start to avoid evaluation errors based on positional inaccuracies.

The light sections 6 projected by the lasers onto the object 4 are recorded by solid-state cameras 7 arranged at an angle α relative to the optical axis or light plane 21 of the laser 5 allocated to the respective camera 7. Each camera 7 may be fitted with a filter 8 which allows only light having the wavelength of the light emitted by the associated laser 5 to pass through, so that each camera 7 can receive light only from the laser light source 5 with which it is paired. This prevents each camera 7 from being influenced by light emitted by other light sources 5. At the same time, a very accurate evaluation can be made of the outline of the strips 6 or the basic data of a calibration object can be accurately evaluated. This also increases the subsequent measuring accuracy.

Appropriate control wires for the light sources 5 or the cameras 7 are indicated by the number 11; the control unit 10, which controls the on/off switching of the illumination and the cameras, can be coupled with the evaluation unit 9 for the camera signals or operates in conjunction with that unit.

The evaluation unit 9 comprises a computer, to which are fed the digitalized video signals from the cameras 7 and which stores these signals. The computer selects from the image matrix those image points which represent the light section. When a measurement is performed, the positional data of the object and the position and orientation of the camera relative to the light plane and also the focal length of the lens are all known, so that the image points which are found can be geometrically rectified and calculated back into the actual coordinates of the object.

It should be noted that in favourable cases, two cameras alone are sufficient to take the measurements; for round cross sections at least three cameras are needed; and when four cameras are used, as shown in Fig. 3, almost all customary structural sections with convex and concave cross sectional shapes can be completely measured, as long as no undercuts exist.

The light sources 5 used may be white light sources, with appropriate colour filters, lasers and laser diodes whose wavelengths or frequencies can be adjusted, or similar. Appropriate optical systems are known for forming the very narrow light sections on the object.

The cameras used may be video cameras, solid-state cameras, especially CCD cameras, and cameras with sensor elements which are specifically colour-sensitive or respond to certain colours, i.e. so-called colour cameras. In particular, imaging is carried out using CCD cameras comprising a solid-state sensor element which is built up from about 500 x 500 photo diodes and supplies substantially distortion-free images.

In order to evaluate the camera video signals stored in the evaluation unit 9, the image is normally scanned for contour starting points by checking the brightness contrasts of the image points and joining up the individual line segments to form traverses. Once the appropriate traverses have been determined, separately for each individual video camera signal, each traverse is transformed into the coordinates of the object and then the traverses obtained from the individual cameras are combined together to give the overall contour from which the desired dimensions are calculated.

The imaging or rectification parameters are determined in the course of the calibration process, for which purpose a calibration body is placed in the measuring field of the cameras and the exact dimensions of the calibration body are stored in the computer. When the light section of the calibration body is recorded in the described manner, the rectification parameters can be calculated by comparing the stored dimensions with the measured light sections.

In Fig. 1, the reference number 12 denotes the unit used to process the signals from the individual cameras into the traverse sections recorded by each camera. Reference number 13 denotes the unit for combining the individual traverses to form the outline or cross section of the object. Reference number 14 is a monitor on which the measured object is displayed, and 15 is a printer for printing out the measurements of the object or other measurement data, and 16 is a plotter for graphically reproducing the measured object.

Figure 2 depicts a spatial arrangement in which the object 4 is illuminated by four lasers 5 and the light sections 6 are recorded by CCD-cameras 7 fitted with filters 8. It can be seen that the optical axes 21 of the lasers 5 and the optical axes 22 of the cameras 7 enclose an angle α of 45°, and the planes of laser light formed by each laser 5 lie in one common overall plane.

Figs. 3a, 3b and 3c show various ways of modifying the imaging scale or of adjusting the measuring field size of the cameras relative to the object to be measured or the calibration object. In Fig. 3a a camera 7 is fitted with a ZOOM lens 18 and it is shown that objects 23 of various size or light sections or light strips 6 of various size, can be imaged in such a way, as shown on the left and right-hand sides of Fig. 3a, that they fill the measuring field 30 or 31 of the camera 7 to the maximum extent possible, or that the size of the measuring field 30 or 31 is adapted to the objects to be measured or to the light strips 6.

Fig. 3b shows an arrangement similar to that in Fig. 3a, wherein a lens-changing device 18′, e.g. a rotating lens turret system, is provided to adapt or vary the imaging scale or the measuring field size of the video camera 7.

In Fig. 3c a camera-displacing device 18" is provided to adapt the measuring field size by varying the distance between the camera 7 and the object 23, although alternatively the object could be moved relative to the camera 7 or both the camera 7 and the object or calibration body 23 could be moved relative to each other.

The same improvement in accuracy when measuring objects can also be achieved when measuring calibration bodies by matching the size of the measuring field to the calibration body or to individual areas thereof. As already mentioned, the measurement system is calibrated using a calibration body of precisely defined shape. By comparing this defined shape with the image data of the measured calibration body stored in the evaluation unit, it is possible to obtain the necessary rectification parameters to rectify images of objects which are to be measured. As is the case when measuring objects, there are errors involved in determining the rectification parameters, depending on the resolving power of the image processing system. As when measuring objects, small errors or calibration errors can be reduced or avoided when measuring calibration bodies, or when carrying out calibration, by ensuring that the light strips generated on the calibration body extend as far as possible over the entire measuring field, or the image or desired section of the image of the calibration body extends over the entire sensor element.

If variable measuring ranges are used, as described above, then it is advantageous, for measuring ranges with different imaging scales, to use different calibration bodies or calibration bodies with specific calibration marks for different imaging scales. According to the invention, calibration bodies for differently sized measuring fields or for different imaging scales may possess different sections with marks indicating predetermined locations and/or predetermined dimensions, and these sections are placed in the measuring field or imaged on the sensor element and their known dimensions are evaluated.

Fig. 4a shows in diagrammatic form the measuring of a calibration body 23′ bearing the calibration marks 26 and 26′. Fig. 4b shows a top view of the calibration body 23′ on which the peripheral calibration marks 26 and the centrally located calibration marks 26′ can be seen. The aiming directions or optical axes of the four video cameras are denoted by the number 22. The calibration body shown in Figs. 4a and 4b is designed for the simultaneous calibration of four cameras. Calibration is carried out by forming appropriate light sections 6 on the calibration marks 26 or 26′, or the calibration marks 26 and 26′ are intersected by the corresponding light planes 33. If the image transmission system is on the "large scale" setting, i.e. if the ZOOM lens is in the "telephoto" position, then as shown in Fig. 4d, only the four central calibration marks 26′ are located in the measuring field and only the light sections 24′ of the central calibration marks 26′ are imaged on the sensor element 34′ of the video cameras 7. When a smaller imaging scale is selected, e.g. when the ZOOM lens is in the wide-angle setting, all the calibration marks 26 and 26′ can be imaged, or the light sections 24 and 24′ are imaged, on the sensor element 34′, as shown in Fig. 4c. By comparing the measuring data from the calibration body with stored data on the dimensions of the calibration marks, the evaluation system can determine the imaging scale or the image field size; in addition, by measuring the light strips, the evaluation system can determine the size of the object and measure the latter with the two imaging scales. In this way, the measurement error and the calibration measurement error can be reduced in absolute terms, and the measuring accuracy can be increased.

Advantageously, the imaging scale selected should be as large as possible. The imaging scale used for the measurements should be known. Measuring is carried out either at the same imaging scale used for calibration, or the imaging scale used for the measurements is adjusted to a known value either automatically by the evaluation unit or manually.

A further improvement in the measurement or calibration process is achieved when a light strip is projected on an elongate object, e.g. a ruler or measuring rod, and measurements are taken across the planes of the measuring field. The object is then shifted to a parallel position and again measured; this process is repeated until light strips have been measured at regular intervals across the measuring field. The object (ruler) is then rotated through 90° and the same process is repeated. This measurement grid, the spacing of which can be varied depending on the measuring accuracy desired, is used for calibration and is related to the image of the object or is compared with the light strips projected onto the object. If certain areas of the object have to be measured more accurately than others, a narrower grid is formed in those particular areas. The formation of the grid or of the calibration light strips can thus be locally varied over the measuring field or image field.

Advantageously, according to the invention, the light emitted by the light strip formed on the object is fed directly to the video cameras or is fed directly or without any deflection of the beam path to the sensor element by the imaging devices 18, 18', 18" provided. According to the invention, the size of the light section(s) is directly matched to the size of the sensor element, or vice versa, so that light losses are prevented and the evaluation can be improved and made more accurate by an imaging scale, which can be varied during the measurement process itself. It is thus possible, by quickly modifying the imaging scale, to measure one and the same light section in various sizes or in more or less image-filling form, or to examine desired detailed areas using a particular desired imaging scale. Since each video camera is equipped with such variable imaging units, it is also possible to image and evaluate the light sections allocated to each video camera, using different imaging scales.

CLAIMS

1. A process for optoelectronically measuring the shape, in particular the cross sectional shape, of objects, e.g. workpieces, or for calibrating optoelectronic measuring devices, wherein at least one light strip is projected in each case from at least one light source, preferably a laser light source, onto the object to be measured and/or onto the calibration body (light section process), and the light strips are recorded by at least the same number of video cameras, preferably CCD solid-state cameras, as there are light sources and are imaged on the sensor elements of the cameras, and the camera signals are fed to an evaluation unit comprising a computer for the purpose of image evaluation and for calculating the dimensions of objects or for determining the basic data and parameters needed for calibration, characterized in that in order to approximate or adapt the image size of the respective light strip(s) to the size of the respective sensor element, the imaging scale is modified or varied, or the size of the measuring field of the respective camera is varied as a function of, or adapted to, the size of the light strips generated on the object and/or calibration body.

2. A process according to Claim 1, characterized in that in order to modify the imaging scale of the light strip(s) imaged on the sensor element, or in order to modify the size of the measuring field, ZOOM devices fitted to the video cameras can be adjusted, possibly by means of a motor drive, and/or camera lenses with different focal lengths may be fitted to the video cameras and/or the distance between the video cameras and the object to be measured and/or the calibration body may be modified, possibly by means of a motor drive.

3. A process according to Claim 1 or 2, characterized in that when performing the measurements and/or the calibration, all the light strips formed on the object, or all the light strips formed on the calibration body or on calibration marks are imaged with one size on the sensor element, and further characterized in that the light strips imaged on the sensor element fill

the area of the latter to the fullest extent possible, or the size of the measuring field is just large enough to include all the light strips.

4. A process according to one of the Claims 1 to 3, characterized in that by measuring the light sections imaged on the sensor element in the evaluation unit, it is possible to determine the enlargement or reduction scale selected for imaging the respective light strip on the object and/or calibration body and this scale is then taken into account when evaluating the camera signals.

5. A process according to one of the Claims 1 to 4, characterized in that in order to perform the calibration, at least one light strip generated on a calibration body of given size is measured, and the imaging scale data derived from the imaging of at least this one light strip on the sensor element are stored in the evaluation unit and used when measuring an object with the same imaging scale, or with an imaging scale deviating in a known or predetermined manner therefrom, to determine the actual size of the light strips generated on the object.

6. A process according to one of the Claims 1 to 5 characterized in that at least one light section formed on a calibration body or on a calibration mark is imaged on the sensor element, and the size of the image of at least the one light section strip is adapted to the size of the sensor element, and the light strips generated on the calibration body or on the calibration marks are measured and the imaging scale or the size of the measuring field are determined, and the data and parameters relating to the size of the light strips and of the imaging scale are stored in the evaluation unit, and when measuring at least one light strip generated on an object, the size of the image of at least the one light strip is matched to the size of the sensor element, and using the same imaging scale or an imaging scale deviating in a known or predetermined manner therefrom, the object is measured using this imaging scale, and the dimensions of the object are calculated with the aid of the imaging parameters determined during the measuring and calibration processes.

7. A process according to one of the Claims 1 to 6, characterized in that light strips generated on at least one calibration body with given calibration marks, preferably peripheral and central calibration marks of predetermined size, are measured using at least two different imaging scales or measuring field sizes, and the data obtained from the respective images of the light strips on the sensor element are stored in the evaluation unit, and when the object is measured, then -possibly on the basis of comparing the size of the image of the light strips generated on the object with the available size of the sensor element, taking into account the imaging scale used for calibration - the imaging scale or the measuring field size is modified, in particular automatically, and the size of the image of the light strips generated on the object is as closely as possible approximated to the size of the sensor element, or the largest possible measuring field size is selected from which calibration data are stored in the evaluation unit.

8. An arrangement for optoelectronically measuring the shape, especially the cross sectional shape of objects, e.g. workpieces, or for calibrating optoelectronic measuring devices, wherein in each case at least one light strip is projected onto the object to be measured and/or onto the calibration object from at least one light source, preferably a laser light source (light section process), and the light strips are recorded by at least the same number of video cameras, preferably CCD solid-state cameras, as there are light sources, and are imaged on the sensor elements of the cameras which are connected to an evaluation unit comprising a computer for image evaluation or for calculating the dimensions of the object or for determining the basic data and basic parameters needed for calibration, in particular for carrying out the process according to one of the Claims 1 to 7, characterized in that devices (18, 18', 18") are provided for modifying or varying the imaging scale of the light strip(s) imaged on the sensor element, and by means of these devices the image size of the light strips can be altered and in particular adapted to the size of the respective sensor element (34), or devices (18, 18', 18") are provided for modifying the measuring field size of the cameras (7) and for adapting the measuring field size to the

light strips to be measured on the objects (23) or on areas of the objects and/or on calibration bodies (23′).

9. An arrangement according to Claim 8, characterized in that in order to modify the imaging scale or the measuring field size, the video cameras (7) are fitted with ZOOM devices (18) which are adjustable, possibly by means of a motor drive, and/or the video cameras (7) may be fitted with lenses (18′) having different focal lengths, and/or devices (18") are provided for varying the distance between the video cameras (7) and the object to be measured (22) and/or calibration bodies (23′).

10. An arrangement according to Claim 8 or 9, characterized in that the evaluation unit (9) comprises a comparator or processing unit for data and parameters obtained from at least one measured calibration body (23′) and for data and parameters supplied to the evaluation unit in the course of the measurement of an object (23), and the evaluation unit (9) is connected to the devices (18, 18′, 18") for modifying the imaging scale or the measuring field size, and these are fed with a control signal, depending on the result of the comparison or processing, to adjust the imaging scale or the measuring field size.

11. An arrangement according to one of the Claims 8 to 10, characterized in that at least one calibration body (23′) is provided with given calibration marks differing as to position and/or size, e.g. peripheral and central calibration marks (24, 24′), and it can be imaged in various sizes on the sensor element (34).

12. An arrangement according to one of the Claims 8 to 11, characterized in that for calibration purposes a long object in relation to the measuring field, e.g. a ruler, a measuring rod, or similar, is provided on which light strips are generated, and the object can be arranged in various parallel positions over the measuring field, and the light strips generated on the object are measured, and this measurement is repeated using an object rotated by 90°, and in both cases the distances between the positions of

the objects, or the positions of the object, are known, and the parameters and data relating to the object are derived from the positions of the light strips and used as the basis for measuring the object or for evaluating the light strips formed on the object.

Summary

In a process for optoelectronically measuring the shape of objects, the object (4) to be measured is illuminated by laser light sources (5), whose light beam is spread into a plane by means of an optical system, which is not depicted, so that a bright strip (6) is formed by each laser light source (5) on the object (4), and the strips as a rule partially overlap. Each strip (6) is recorded by a solid-state camera (7) fitted with a filter (8) which allows only the light emitted by the associated laser (5) to pass through. The laser light sources (5) are connected via control wires (11) with a control unit (10) which is coupled with an evaluation unit (9). The evaluation unit (9) comprises a computer to which the digitalized video signals from the cameras (7) are fed. Reference number 12 denotes a unit for processing the signals of the individual cameras (7) into the line segments recorded by each camera, and (13) is a unit for combining the individual traverses together to form the outline of the object; (14) is a monitor for displaying the measured object; (15) is a printer for printing out the dimensions of the object; and (16) is a plotter for graphically recording the object. In order to approximate or adapt the image size of the respective light strip (6) to the size of the respective sensor element of the solid-state camera (7), the imaging scale is modified or varied or the measuring field size of the respective camera (7) is varied as a function of, or adapted to, the size of the light strips (6) generated on the object (4).

(Fig. 1)

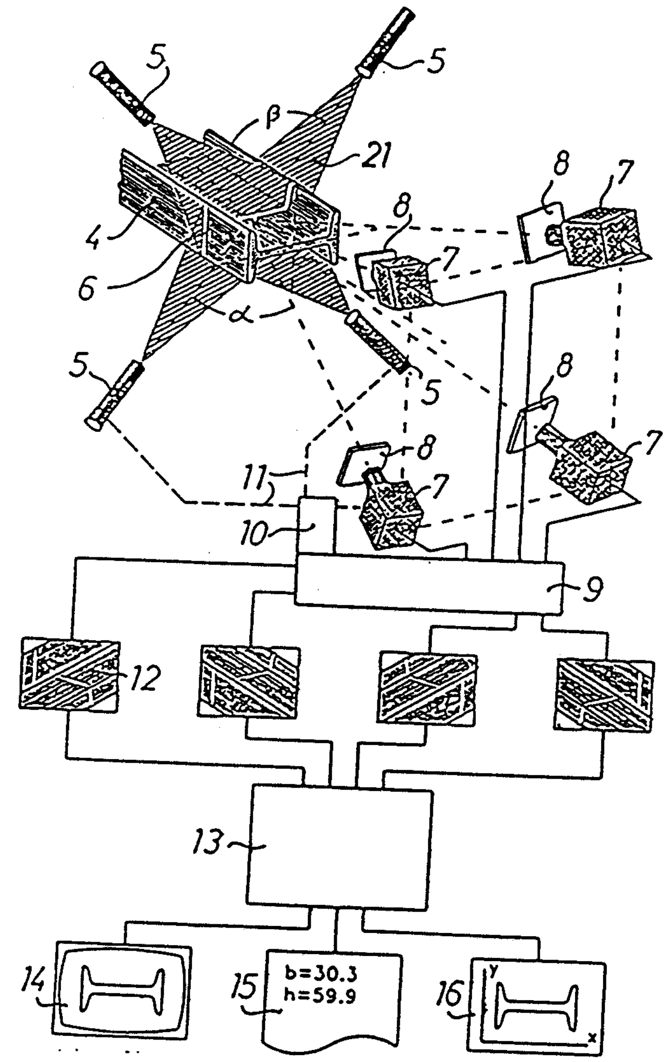
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Fig. 1

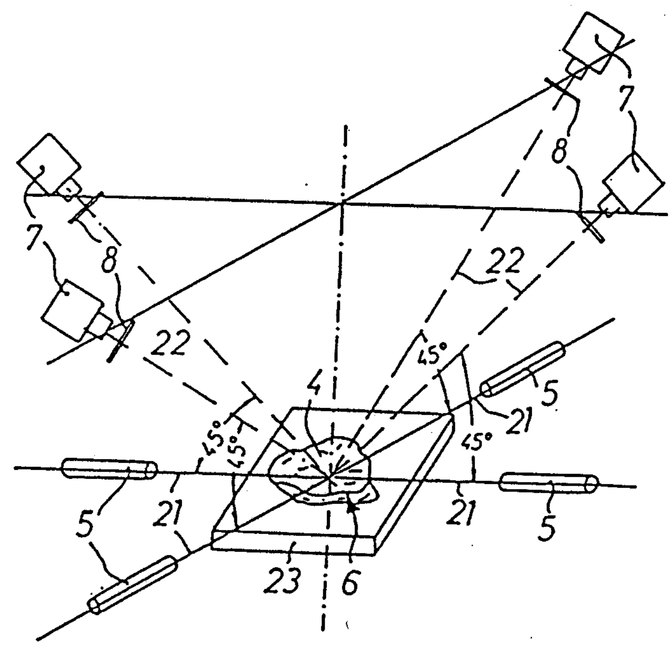
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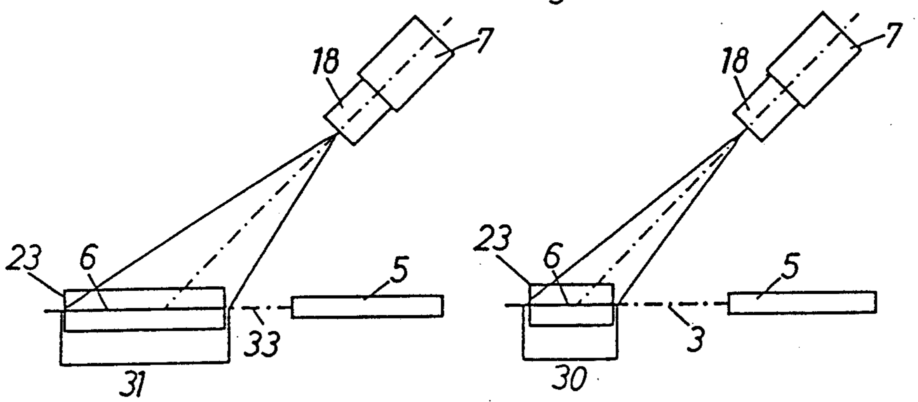
Fig. 2

Fig. 3a



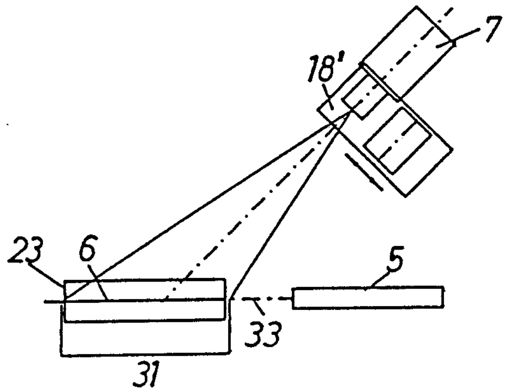


Fig. 3b

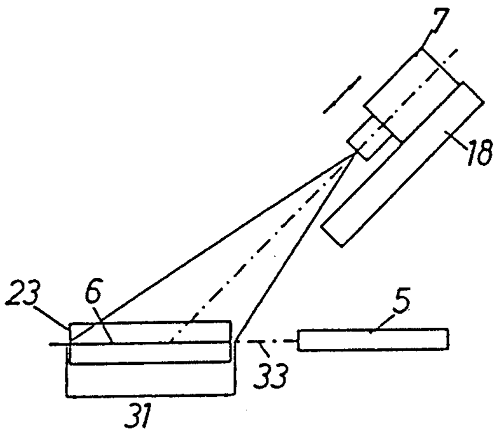


Fig. 3c

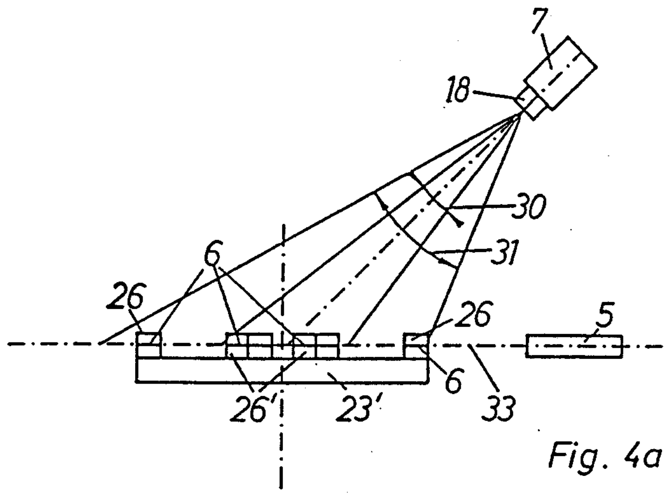


Fig. 4a

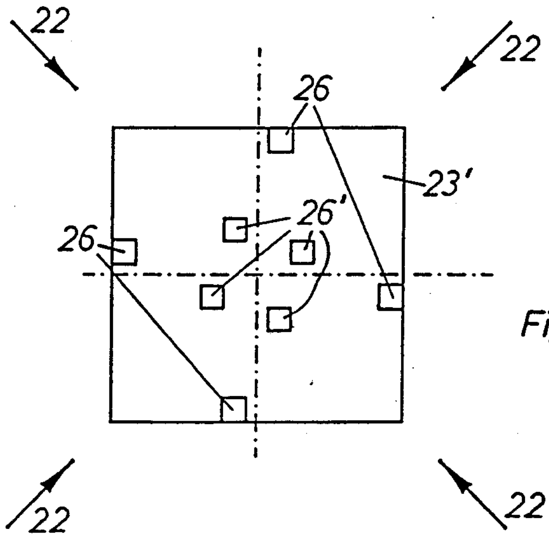


Fig. 4b

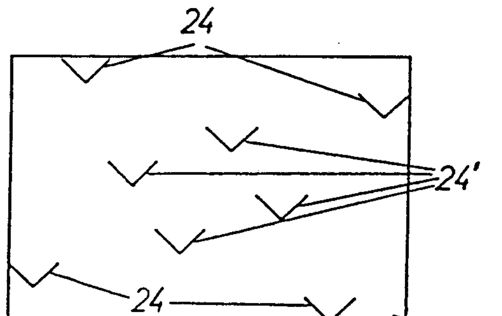


Fig. 4c

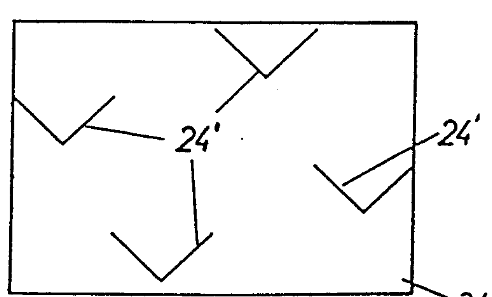


Fig. 4d