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MEASURING POSITIONS OR COPLANARITY OF CONTACT ELEMENTS OF AN ELECTRONIC COMPONENT WITH A FLAT ILLUMINATION AND TWO CAMERAS

The present invention relates to a method for measuring
5 respective positions of a set of N contact elements of an electronic
 component.

 According to the state of the art, the contact elements of the
electronic component are illuminated by means of a light source and a
camera is used to record an image of the contact elements. The
10 positions of each of the contact elements are determined by using the
 recorded picture. The determination of these positions is important for
 the computation of the coplanarity of contact elements of electronic
 components such as BGA (Ball Grid Array)/CSP (Chip Scale Packaging)
 and flip-chip devices. If that coplanarity is not within predetermined and
15 limited constraints, the necessary electrical contacts can not be made
 and the electronic component is useless.

 A drawback of the known method is that, in order to
determine the height of the contact elements, it is necessary to move
either the camera or the light source. This renders measurements on the
20 fly impossible.

 It is an object of the present invention to provide a method
for measuring positions of a set of contact elements of an electronic
component, without moving either the camera or the light source.

 For this purpose a method according to the present
25 invention is characterised in that it comprises :

- bringing said set of elements in a measurement plane;
- illuminating said measurement plane by means of a substantially
homogeneous light source producing a light with an incident angle on
said elements of at the most 20°;

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- recording a first image of said elements by means of a first camera having a first image plane extending substantially in parallel with said measurement plane;
- 5 - recording a second image of said elements by means of a second camera set up over a triangulation angle α with respect to said first camera and said measurement plane, said triangulation angle being situated between 25° and 80° ;
- 10 - determining within said first image for each i^{th} ($1 \leq i \leq N$) element, a first image point X_1 of a first reference point situated on each of said elements;
- determining within said second image a second image point X_3 by mapping with respect to a calibration plane each time said first image point X_1 into said second image;
- 15 - determining within said second image, a third image point X_4 being the image of said first reference point;
- determining within said first image a fourth image point X_2 by mapping said third image point into said first image;
- determining within said first image a displacement Δx_i between said first and fourth image point.
- 20 The first image enables to determine the X and Y position whereas the second image, in combination with the first, enables to determine the Z position or height. Since two cameras are used, it is no longer necessary to move the light source or the camera. Since the two cameras are set up according to a triangulation angle with respect to each other, some
- 25 distortion occurs in the second image recorded by the camera. This is however mathematically corrected as the angle is known between the two cameras. The use of a light source producing a light with an incident angle of at the most 20° enables to illuminate the component with a same light source for both cameras.

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A first preferred embodiment of a method according to the present invention is characterised in that said first X_1 and third image point X_4 are determined by means of a convolution operation with a predetermined convolution pattern. The use of a convolution pattern
5 enables an easy and reliable subpixel calculation based on the grey values of the pixels in the recorded first and second image.

A second preferred embodiment of a method according to the present invention is characterised in that said convolution pattern is a circle for said first image, and an ellipse shaped curve for said second
10 image. Those convolution patterns fit with the images recorded when the triangulation angle is approximately 45° .

A third preferred embodiment of a method according to the present invention is characterised in that said reference point is situated offset of a top of said element. With the incident light and the chosen
15 triangulation angle the top of the element can not be reached exactly. Therefore, a point offset with respect to the top is considered. However as this is done for all the elements and as only the relative position is of importance, this choice fits with the chosen methodology.

The invention also relates to an apparatus for measuring
20 respective positions of a set of contact elements of an electronic component.

The invention will now be described in more details with reference to the drawings. In the drawings :

figure 1 illustrates schematically the set-up of the
25 illumination and the cameras according to the present invention;

figure 2 shows an example of a first and second image such as recorded by the first and second camera;

figure 3 a + b illustrates schematically how the light originating from the light source is reflected towards the first camera;

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figures 4 and 5 illustrate schematically the reflection of the light towards the second camera;

figure 6 illustrates the mapping of co-ordinates from the first to the second calibration image;

5 figure 7 illustrates the different steps of the measurement principle according to the invention;

figures 8 and 9 illustrate the convolution procedure applied on the first and second image;

10 figures 10 and 11 illustrate a first and a second embodiment of an apparatus according to the present invention; and

figure 12 illustrates the optics of a tilted image plane.

In the drawings a same reference sign has been assigned to a same or analogous element.

The method according to the invention is designed for the
15 automatic computation of the coplanarity of contact elements of electronic components such as BGA (Ball Grid Array)/CSP (Chip Scale Packaging) and flip-chip devices. As illustrated in figure 1, the electronic component 1 is placed in a measurement plane, in such a manner, that its N contact elements 2 are illuminated by an illumination source 5. The
20 latter produces a homogeneous illumination of the contact elements at a low incident angle β , which is at the most 20° . Preferably, the light illumination source comprises a high-quality ring-light illumination source. Such a source is built up of a series of LED's which are disposed in a ring, square, hexagonal or other substantially planar geometrical
25 arrangement situated under the plane in which the contact elements are placed. It is important that a substantially homogeneous light field 6 is created which covers the volume in which the contact elements 2 of the component are located. In such a manner, a substantially homogeneous illumination of different contact elements is obtained. In order to obtain a

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symmetrical illumination, the amount of the angle will be determined by the dimension of the component to be measured. The larger the component, the larger the angle. So for example for a component of 40 x 40 mm, the diameter of the ring will be 15 cm and $\beta = 15^\circ$ whereas for a
5 component of less than 15 x 15 mm, $\beta = 10^\circ$.

Since the light source 5 illuminates the surface on which the contact elements are placed from the peripheral of the surface, the sides of the contact elements, generally formed by balls, are illuminated. A first camera 3 and a second camera 4, placed under the measurement
10 plane where the electronic component is situated, record the light reflected by the contact elements. The cameras are preferably CCD cameras. The first and second camera are set up in such a manner as to make a triangulation angle α with each other and with respect to the measurement plane, which angle is situated between $25 \leq \alpha \leq 80^\circ$,
15 preferably 45° for facilitating the calculation as will be described hereinafter.

Since the side of the ball-shaped element or even Gull-Wing or rectangular shaped element is illuminated, the first camera will record a characteristic doughnut-shape first image as shown in figure 2. It
20 should be noted that the black parts in that figure 2 show the reflected light, whereas the white parts show the absence of reflection. However in case of a damaged element, the doughnut-shape rapidly degrades due to scattering of the light on the damaged surface.

As is illustrated in the figure 3 b, an incident light ray i_1 ,
25 generated by the illumination source 5 hits the contact element 2 in a point Q and is reflected as a reflected ray r_1 towards the first camera 3 where the first image is formed. Due to the set up of the illumination source and the first camera, a light ray i_p incident on the point P situated on top of the ball is not reflected towards the first camera. Thus as

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illustrated in figure 3a, only the light incident on the ring shaped areas s_1 and s_2 , on the ball surface will be reflected towards the first camera, leading to the doughnut structure of the first image. Such a set up provides a high image quality with no influence of the substrate on which the contact elements are placed and which substrate is generally made of plastic or ceramic material. As the centre of the first image corresponds to the position P, the X and Y co-ordinates of the latter can be measured.

Because the ball surface could be somewhat irregular, the reflections could be somewhat diffused. This signifies that a reflection cone is formed instead of an ideal reflected light ray. This cone has a highest intensity along the ideal reflection angle and which diminishes when deviating from that ideal reflection angle. The opening angle of this cone depends on the ball surface properties. If the reflectivity is high, a narrow cone is formed, when not, the reflected light becomes more diffuse. In practice this means that the reflected light is observed over a wider range, strongest at the theoretical ring and diminishing towards the centre and the outer edge of the ball. A second factor is that the illumination source has a finite size and therefore generates a bundle of light rays with slightly different angles of incidence which are typically in the order of magnitude of 4-6°.

As illustrated in figures 4 and 5, the second camera sees light reflected from another part of the contact element than the one recorded by the first camera, which leads to the fact that the black spot and the doughnut shape are situated at a different place in the second image recorded by the second camera. The latter records in particular light reflected by the bottom part of the contact element. In reality, the strongest reflection is a bit further up the slope of a right side of the ball and the dark spot moved towards the left offset with respect to the

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centre. This explains why an asymmetrical reflection is obtained in the second image.

The light path travelled by an incident ray i_2 and reflected towards the second camera is shown in figure 5. The incident ray i_2 hits the ball on a point Q_2 which is not situated at the bottom of the ball but offset over a distance z considered in Z direction. Incident ray i_2 is reflected as reflected ray r_2 towards the second camera. Suppose now that the triangulation angle α between the first and second camera is : $\alpha = 90^\circ - \beta_1$ and that the ball has a radius of $r = 375 \mu\text{m}$. Suppose also that

incident angle $\beta_2 = 15^\circ$. Since $2\beta_4 + \beta_1 + \beta_2 = 180^\circ$, $\beta_4 = \frac{1}{2}(180 - \beta_1 - \beta_2)$.

Further since $\beta_3 + 90^\circ + \beta_2 + \beta_4 = 180^\circ$, $\beta_3 = 90 - \beta_4 - \beta_2$.

Thus $\beta_4 = 60^\circ$ and $\beta_3 = 15^\circ$.

Now the displacement in horizontal direction dx can be calculated $dx = r \cdot \sin \beta_3 \Rightarrow dx = 97 \mu\text{m}$.

The distance z can now be calculated as follows $r = Z + r \cos \beta_3$ thus $z = r(1 - \cos \beta_3)$ with $\beta_3 = 15^\circ$, $z = 12.7 \mu\text{m}$.

So instead of measuring the bottom of the ball, a position which is at $12.7 \mu\text{m}$ inside the ball is measured. But since coplanarity is a relative measurement, the displacement z is nearly equal for all the contact elements to be measured and the coplanarity of the ball can be accurately measured despite the fact that a position inside the ball is considered.

The point Q to be measured on the ball surface will thus form an image point Q' in the second image, thus enabling to determine that position Q' in the second image. The position of Q' will on its turn enable to determine the Z co-ordinate of the contact element.

With the measurement principle according to the present invention, the centre of each i^{th} contact element ($1 \leq i \leq N$, where N is the

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total number of contact elements) is reconstructed by means of the first image whereas the second serves to determine the top of the ball surface of each i^{th} contact element. That the second image shows a widening matrix of doughnuts and black spots is due to the triangulation angle at which the second camera is set up. The more the contact element is distant from the image field of the second camera, the larger the distance will be between neighbouring images of the contact elements. This phenomenon, known as perspective distortion, can however mathematically easily be taken into account as it is completely determined by the dimension of the component and the position of the second camera and the lens characteristics. Another technique for eliminating the perspective distortion is the use of a tele-centric lens.

Before the measurement of the respective positions of the contact elements of an electronic component can be started, it is necessary to calibrate the apparatus in order to establish a relationship between a position x_1 in the first image and a corresponding position x_2 in the second image. In such a manner, a mapping algorithm can be determined enabling a mapping between both images. Figure 6 illustrates that calibration. A calibration plate comprising a number of predetermined, accurately known positions, represented for example by crosses, is defined. That plate is for example made of a substrate which is placed at the location provided for installing the electronic component to be measured. The substrate is for example made of glass on which the crosses are printed by using a highly accurate screen printing process. The first and second camera each record then a respective calibration image of that calibration plane, as shown in figure 6. For the latter measurement, it is not necessary that the calibration plane and the plane in which the contacts are situated are exactly corresponding, since only relative measurements are required.

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In order to compute the co-ordinates in three dimensions of each contact element, the relative position of both cameras will now be determined by using the calibration plate. In order to obtain an accurate calibration, the position and the size of the crosses printed on the calibration plate are preferably known with an accuracy of 0.1μ . The calibration comprises the determination of the position of the crosses in the first and second image such as recorded by the first and second camera. Since the positions of the crosses on the calibration plane are accurately known, their respective positions in the first and second image are obtained by assigning their co-ordinates on the calibration plate to the one in their respective image. In such a manner, a calibration plane is determined in the image field. For all the intermediate points between each rectangle of four crosses, a bilinear interpolation technique is used to determine their co-ordinates. So for example a point X_1 in the first image will be expressed in fractions of dx and dy and considered with respect to the rectangle formed by crosses 11, 12, 13 and 14. In order to match a point in the first image with a corresponding point in the second image, a mapping algorithm is determined, mapping the co-ordinates of for example a point 11 in the first image with the corresponding point 11' in the second image. The position of point X_3 in the second image and which corresponds with point X_1 in the first image is then also expressed in fractions of dx' and dy' .

The calibration procedure thus enables to determine the scaling factors to convert a pixel position in the first or second image to a position of the contact elements on the component. As the position is accurately determined by the calibration plate, the position of the contact elements can also be determined accurately in microns. The calibration procedure also enables to determine a camera to camera calibration, establishing the relation between the first and second camera.

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Now that the calibration plane has been determined and the set-up of the first and second camera has been explained, the measurement principle according to the present invention will be explained. The consecutive steps of the method are shown in figure 7.

5 Suppose that the top of an i^{th} ball shaped contact element is located at a point P with respect to the calibration plane p . From the doughnut shaped first image, as recorded by the first camera, the centre can be determined. This centre corresponds to a pixel situated at a point X_1 in the first image. Thus X_1 gives the position in the first image of a first
10 reference point corresponding to the centre of the i^{th} contact element of the component.

In a second step, the point P is orthogonally projected on the calibration plane giving a point P'. In the second image, as recorded by the second camera disposed over a triangulation angle α , the point X_3
15 is then the image point of position P'. X_3 is thus the expected position in case the ball would be localised in the calibration plane.

In a third step, the position of a point X_4 in the second image is determined by using the light intensity around measurement point Q' (see figure 4). Q' is the predicted position of the top of the ball in
20 the second image. The position of point X_4 is determined by considering the moon-like shaped pattern in the second image which represents the reflection of the top part of the ball. The displacement between X_3 and X_4 is due to the fact that the real contact element is usually not exactly in the calibration plane but at a height difference Δz , which is the one to be
25 measured. In this step the Z tolerance and the tilt of the component are compensated as the measurement is done relatively with respect to the calibration plane which is the same for all the balls of the component.

Now that the position of X_4 is determined, the latter can be mapped into the first image. Therefore X_4 is mapped on the calibration

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plane leading to a point P'' which co-ordinates can be determined by using the calibration algorithm. Indeed, since the co-ordinates of X_4 are known in the second image, they can be mapped on the calibration plane and expressed in fractions of dx' and dy' relative to their appertaining quadrant. Optically, position X_4 is projected on the calibration plane p, leading to the point P'', which on its turn forms a fourth image point X_2 in the first image. The mapping algorithm determined during calibration, now enables to map X_4 into the first image and to determine the co-ordinates of X_2 . This can be done because the scaling factor in the first image, converting the pixel position to the real position in microns of the contact element, is accurately known in the first image. In the second image, the scaling factor varies over the surface of the image because of the large perspective distortion. The distance ΔX between X_1 and X_2 is directly proportional to ΔZ which is the height of the ball to be measured, or the difference between the calibration plane and the top of the ball. Because triangle P P'' S is rectangular with P P'' as hypotenuse, $(P P'')^2 = (PS)^2 + (SP'')^2$ or $(P P'')^2 = (\Delta X)^2 + (\Delta Z)^2$. As relative measurements are only of interest, there is no need to exactly determine ΔZ . So the value of ΔX will thus provide a value for the height of the ball to be measured.

The present method is insensitive for variations in the Z-position of the component and also for tilt. The method can compensate more than 1 mm in X or Y position and up to 10 degrees in rotation. Approximately +/- 400 μ in Z-variation and +/- 1 degree in tilt for the largest devices can be compensated in the vertical direction. For CSP components with body sizes up to 10 mm, tilt can be maximally 2 degrees.

The determination of the co-ordinates of the points X_1 , respectively X_4 in the first, respectively the second image will now be described in more details with reference to the figures 8 and 9. Figure 8a

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shows a doughnut shaped pattern such as recorded by the first camera. The centre of this doughnut should now be determined as it will give a position X_1 corresponding to the centre of the balls. For this purpose, a circular shaped first template as illustrated in figure 8b will be used. The radius of the circular shaped template corresponds to the one of the ball shaped contact element. A convolution operation with that circular shaped first template will then be realised on the doughnut present in the first image.

The first template comprises a set of point pairs of which a "+" point is placed at the inside of the template and a "-" point at the outside of the template. The distance between a "+" point and a neighbouring "-" point is the admitted tolerance of the method. In order to perform the convolution operation, the template is shifted successively over each of the doughnuts of the first image. The template is shifted pixel by pixel over the doughnut and each time the following calculation is performed :

$$k = \sum_{+} \text{greyvalue} - \sum_{-} \text{greyvalue}$$

wherein $\sum_{+} \text{greyvalue}$ respectively $\sum_{-} \text{greyvalue}$ is the sum of the greyvalues of the pixels which coincide with a "+" respectively a "-" on the template. A matrix of k values is thus determined for the pixels of the first image, wherein k_{ij} corresponds to the k value determined when the origin of the template was located at a pixel situated in an i^{th} row and j^{th} column within the first image. The position at which k has the maximum value will then correspond to the position of X_1 , i.e. when all "+" are within the doughnut. This position can be computed with an accuracy of approximately 1/5 to 1/10 of a pixel by using techniques which are based on the interpolation of the result of neighbouring points around the maximum. Of course other techniques such as filtering, edge detection or

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ough transformations could be used instead of a convolution process for determining the co-ordinates.

5 An analogous process is then performed for the second image, however with a moon shaped second template as shown in figure 9b. The choice of the second template is of course related to the shape of the second image (figures 4 and 9a). The elliptical moon-like shaped second template is described by the segment diameter a in horizontal direction and the segment diameter b in vertical direction as well as by the segment angle β defining the spherical part to be used, for example β
10 $= 140^\circ$.

The second template is shifted over the second image in an analogous manner as the first template is shifted over the first image. For each shift step, again a value k is determined and a maximum k value indicates the position of point X_4 in the second image. By using an
15 appropriate interpolation technique, such as explained with reference to the calibration process, it is possible to compute the position of the templates with an accuracy up to $1/10$ of a pixel.

The layout of the measurement apparatus according to the invention is shown in fig. 10. It comprises preferably a stainless steel
20 construction 20 where the illumination source 5, the first camera 3 and the second camera 4 are integrated. Because compactness is required to the limited space restrictions in most handlers, an additional mirror 21 is used to reduce the size of the apparatus. The electrical component to be measured is placed on top of the apparatus in a measurement plane
25 25. The first and the second camera are further connected with a data processing unit (not shown), for example a Personal Computer, provided for processing the data recorded by the cameras according to the principles set out here before.

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The apparatus is insensitive for vibrations due to the rigid construction of stainless steel and due to the short image acquisition times. And even if the chip moves between the first and second image acquisition, this is a relative movement which takes place for all balls and can not be seen in the coplanarity results.

The accuracy of the determination of the position of the contact elements is directly proportional to the angle triangulation α between the first and the second camera. The higher the angle, the better the accuracy will be. In this configuration an angle of approximately 45 degrees has been used. Because of this large angle and because the components can have dimensions up to 40-50 mm, a field depth of 30 mm and more is required. This can normally not be achieved with standard lenses.

Therefore in the present apparatus an additional adaptor part 24 has been mounted between the CCD and the lens of the second camera 4. The adaptor tilts the two planes which respect to each other. As a consequence the image plane will be rotated with respect to the object plane in such a way that the projection is sharp. The physical background is explained with respect to fig. 12.

The upper part of figure 12 shows the projection as it takes place with a standard lens/camera configuration. The bottom part shows the same object but now tilted with an angle of approximately 45 degrees. In order to achieve a sharp image in the image plane, the CCD must be rotated. This is accomplished with the adaptor part. The adaptor part ensures that the image of the component seen under 45° is completely in focus. This is compensated by using the calibration techniques as explained hereabove. A similar set-up can be achieved by using a tele-centric lens which has the additional advantage of eliminating the perspective distortion.

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Fig. 11 also shows the integration of a coaxial illumination 22 in the measurement apparatus. Although this is not immediately required for the reconstruction method of the balls, according to the invention it is useful for the following reasons :

- 5 1) the coaxial illumination 22 in combination with the half transparent mirror 23 enables a visualisation of the area between the balls. In such a manner it becomes possible to detect solder or dust particles, which could be present in the area between the contact elements;
- 2) it will also allow, in combination with the ring-light under an oblique
10 angle to detect damaged and smashed balls due to probe pins;
- 3) last but not least, the coaxial illumination provides a suitable way to illuminate the calibration plate during the calibration.

The coaxial illumination is preferably placed under the mirror 21 enabling to provide sufficient space for placing the half
15 transparent mirror 23 without interfering with the other mirror 21 and the illumination source 5. The half transparent mirror reflects the light from the coaxial illumination 22 towards the component 1 and enables light, reflected by the component, to cross that mirror and reach the cameras 3 and 4.

20 According to the present invention, it is either possible to acquire the first and second image separately or, since a same illumination source 5 is used for both images, to acquire them simultaneously. The acquisition time will be in the order of 70 ms. So both cameras can be triggered separately or simultaneously. As both
25 images can be recorded simultaneously, they can be acquired "on the fly" which is important for reducing the integration complexity and for reducing standstill time. Thus the components can successively be presented. The processing of each image has to be done separately,

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starting with the first image, as the data of each image is necessary to obtain the required position of the electronic component.



CLAIMS

1. A method for measuring respective positions of a set of N contact elements of an electronic component, said method comprises :
- bringing said set of elements in a measurement plane;
 - 5 - illuminating said measurement plane by means of a substantially homogeneous light source producing a light with an incident angle on said elements of at the most 20°;
 - recording a first image of said elements by means of a first camera having a first image plane extending substantially in parallel with said measurement plane;
 - 10 - recording a second image of said elements by means of a second camera set up over a triangulation angle α with respect to said first camera and said measurement plane, said triangulation angle being situated between 25° and 80°;
 - 15 - determining within said first image for each i^{th} ($1 \leq i \leq N$) element, a first image point X1 of a first reference point situated on each of said elements;
 - determining within said second image a second image point X3 by mapping with respect to a calibration plane each time said first image point X1 into said second image;
 - 20 - determining within said second image, a third image point X4 being the image of said first reference point;
 - determining within said first image a fourth image point X2 by mapping said third image point into said first image;
 - 25 - determining within said first image a displacement Δx_i between said first and fourth image point.
 - determining from said displacement Δx_i and said first image point the position of said i^{th} element.



2. A method as claimed in claim 1, characterised in that said first X1 and third image point X4 are determined by means of a convolution operation with a predetermined convolution pattern.

5 3. A method as claimed in claim 2, characterised in that said convolution pattern is a circle for said first image and an ellipse shaped curve for said second image.

4. A method as claimed in any one of the claims 1 to 3, characterised in that said reference point is situated offset of a top of said element.

10 5. An apparatus for measuring respective positions of a set of N contact elements of an electronic component, said apparatus comprises an illumination source provided for illuminating a measurement plane in which said contact elements are to be disposed, characterised in that said illumination source is provided for generating a
15 substantially homogeneous light source with an incident angle of at the most 20° on said elements, said device further comprises a first and a second camera set up over a triangulation angle α with respect to each other and said measurement plane, said triangulation angle α being situated between 25° and 80°, said first and second camera being
20 provided for recording a first and second image respectively, said first and second camera being connected to a processing device provided for retrieving a first position X1 and a third position X4 from said first and second image and for determining said position from said first and third position.

25 6. An apparatus as claimed in claim 5, characterised in that it comprises a mirror and wherein said mirror and said second camera are positioned in such a manner as to orient light reflected by said component into said second camera.

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7. An apparatus as claimed in claim 6, characterised in that said second camera comprises an adapter part placed between an image plane and a lens of said second camera.

8. An apparatus as claimed in any one of the claims 5 - 7,
5 characterised in that it comprises a coaxial illumination.

