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An Automated Inspection System

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An automated inspection system for manufactured parts is proposed using a cloud of 3D measured points of a part provided by a range sensor, and its CAD model. In spite of the high precision attained by coordinate measuring machines (CMM), range sensors offer significant advantages for dimensional inspection: a high speed of digitisation and the capacity to take 3D measurements on the whole surfaces of a part without physical contact. The system first registers a cloud of 3D points with a CAD model of the part, then segments the 3D points in different surfaces by using the CAD model, and finally measures the control of the specified tolerances on the part. Results of the inspection are displayed in two ways: visually, using a colour map to display the level of discrepancy between the measured points and the CAD model, and a hardcopy report of the evaluation results of the tolerance specifications. Two range sensor technologies have been tested and inspection results are compared with the results obtained with a CMM.

Keywords: CAD based vision; Inspection; Range image; Registration; Segmentation

1. Introduction

The unavoidable inaccuracy of the manufacturing process makes it impossible to obtain a part with rigorous conformity to the specifications. The designer, conscious of this problem, introduces tolerances on each effective dimension of the part, so that it can fulfil its function correctly. Inspection is the process by which a real product is compared with the specifications defined at the design stage.

In industry, inspection is usually performed by human controllers, based on a sampling of parts rather than on the total production, because of the reduction in time and cost. However, in certain critical applications such as for the aerospace or medical industries, all of the parts must be inspected because even the smallest defect is unacceptable and must be identified.

Automated inspection is desirable because:

1. Human inspectors are not always consistent in the evaluation of the products, partly because of tiredness. Some inspection tasks are time consuming, which increases the production cost.
2. Automatic inspection makes it possible to inspect objects in places that are dangerous for humans.
3. In addition, the constant improvement of high-speed production technologies dictates a need for new fast inspection techniques. Indeed, the fast development of products (rapid prototyping) is able to produce real parts starting from CAD models and allows the manufacturing of products of great complexity at high speed.

Thus, in this context of fast production, it is necessary to develop new methods of inspection, which complement the fast rate of production.

At present, most of the automated inspection systems use contact devices, which require that the part be stationary and carefully placed. In industry, the standard machine for the inspection of parts is the coordinate measuring machine (CMM). A CMM is a reliable and precise system of measurement, composed of electronic contact sensors, a software user interface for data input, and an information processing system. Measured 3D data is used by various algorithms to compute the position and the characteristics of the part. Consequently, tolerances can be programmed, computed, and verified.

However, the use of contact sensors has the major disadvantage that it may damage the surface of the product. The development of inspection systems using computer vision sensors, which can be applied for measurements without contact, is mandatory for the inspection of parts built of soft material. Vision-based inspection can also reduce the need to stop the production line and for precise positioning. Many vision-based inspection systems use binary images for the inspection (industrial objects which can be represented by their silhouette). However, the inspection of parts which have variable height,

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deformations or relief require the precise measurement of depth, therefore 3D vision systems are more appropriate. Optical systems, such as laser-based sensors, in addition to providing a range image (without contact), allow a great density of measurement points in a short time (20 000 points per second), which is currently impossible with CMMs. CMMs are capable of a much higher precision, but recent progress in commercial optical systems allows the range sensors to measure parts with an accuracy of about 25 μm, which is sufficient for a large number of industrial applications.

The interest in using CAD models in inspection arises because they represent an exact description of the object. They contain a mathematical description of the shape of the object including an explicit parameterisation of the form of the surfaces and an explicit coding of the relationship between the surfaces. Another advantage of CAD models is their great flexibility, which makes it possible, for example, to add, without problem, a new object in the inspection system.

Usually, only some surfaces of an industrial part are affected by geometrical tolerances. Thus, the problem in this work is to define a methodology to control those tolerances using the 3D data obtained using a range sensor and the CAD model of the part. The inspection method must allow checking of parts with simple or complex surfaces. Such a sensor provides a cloud of 3D points (3D image) in which measured points belong to several surfaces; consequently, registration and segmentation processes are required. We present in Section 2 a registration process between the 3D image of a part and its CAD model. The segmentation process of the cloud of 3D points is discussed in Section 3. In Section 4, the definitions and the methodology to control the specified tolerances are presented. Finally, the results of the inspection using this methodology are presented in Section 5.

Newman and Jain [1] report a survey related to the inspection process, where the problem is tackled from the point of view of irradiance images (grey-level or binary), range images, or other sensing modalities. They discuss the general benefits and feasibility of automated visual inspection and present an unified approach to visual inspection and also consider the specification and analysis of dimensional tolerances and their influence on the inspection task.

The system developed by Newman and Jain [2] permits the detection of defects in a range of images of castings. This system uses CAD model data for surface classification and inspection. They report several advantages for the use of range images in inspection, namely, that they are insensitive to ambient light, that the objects can usually be extracted from their background more easily, that depth measurement is accurate, and most importantly, that range images are explicitly related to surface information. The authors show how a CAD database is used to carry out the control task. They also show the weakness of the current CAD systems in making automatic checks. The authors do not discuss tolerance control. Tarbox and Gottschlich [3] report a method based on comparing a volumetric model of a reference object to a volumetric model of the actual object, iteratively created from sensor data. To provide a framework for the evaluation of volumetric inspection, they have developed a system called IVIS (integrated volumetric inspection system). They obtain a volumetric image of the defects by using custom comparison operators between the reference model and the model of the analysed part. However, they do not control geometrical or dimensional tolerances specified for the industrial part. Trucco et al. [4] report an inspection system that involves the location of the part, the optimal planning for the sensor placement, and the measurement of some geometric characteristics based on the CAD model. The inspection process uses the surface normal vector and focuses on the measurement of shapes such as the flatness of a surface, the angles between surfaces, and the diameters of holes. In this work, we expand the methodology for any kind of tolerance.

2. The Registration Method

After digitalization of the part, we have two sets of data, the CAD file resulting from the design, and the cloud of 3D points. These data are expressed in their own reference systems. The operation, which consists of superposing these two sets, is called registration. The registration of two shapes is defined as finding the 3D rigid transformation (rotation + translation) to be applied to one of the shapes to bring it into a common Cartesian coordinate system with the other. The registration problem has been analysed by several researchers [5–8]. The registration process in this paper relies on the well-known work of Besl and McKay [9] who in 1992 developed a general-purpose representation method for the accurate and computationally efficient registration of 3D shapes, including freeform curves and surfaces. The method is based on the iterative closest point (ICP) algorithm, which requires only finding, for a given point, the closest one belonging to a geometric surface. The rigid transformation is computed using a unit quaternion. However, as the transformation estimate is carried out by a mean square (MS) distance computation, this method is not robust for outlying points, generated either by noise or by the presence of other parts in the scene. As a solution to this problem, Masuda and Yokoya [10] estimate the rigid motion between two range images in a robust way by fusing the ICP algorithm with random sampling and a least median of squares (LMS) estimation. They demonstrated that registration between two images can be achieved with a high level of robustness (up to 50 %) to occlusion and noise. Moron et al. [11,12] implemented an algorithm for registration between an unordered cloud of 3D points and a CAD model in STL or NURBS (non-uniform rational B-splines) format. In the registration process, Moron use the CAD model in the STL format rather than in the NURBS format, so that a little precision is lost but computation time is considerably improved.

3. 3D Data Segmentation

In the registration process, we superposed the CAD model with the 3D data of the part. However, because we are interested in inspecting some specific surfaces, we must segment the part into its different surfaces. The 3D cloud is segmented by computing the distance between every 3D point and all of the surfaces in the CAD model, and by comparing some local geometric properties, between each 3D point in the cloud, and its closest point on the surface. In the CAD model, all the surfaces of the part are defined as parametric NURBS surfaces.

3.1 3D Point/NURBS Surface Distance Computation

The distance of a point to a NURBS surface can be computed as follows. Find a point on the parametric space of the surface (u_0, v_0) such that the distance between the surface $\mathbf{s}(u_0, v_0)$ and the 3D point $\mathbf{r}$ is minimum in a direction perpendicular to the tangent plane at the point. For a detailed computation see [13].

3.2 Geometric Properties Computation and Comparison

Let P be a point from the 3D range data, and Q the closest point to P on the surface. To terminate the segmentation process, we estimate and compare some local geometric properties of P and Q. The geometric properties that we estimate are, the surface normal, the Gaussian curvature and the mean curvature of Q, which are estimated using the NURBS CAD model. We estimate the local geometric properties of P by using the method proposed by Boulanger [14]. Finally, we compare the local geometric properties of Q, estimated from the NURBS surface, to P from the 3D range data.

Figure 1 shows some segmentation results obtained with the segmentation methodology explained in this section.

4. Tolerance Definitions and Control

Many workers [15–17] have focused on the problems of creation and analysis of the tolerances in CAD for solid or surface representation, because there is not a robust method for the definition of those tolerances. A survey on the developments in this field can be found in [18]. We took as a starting point this work for the definition of the tolerances, but we apply it in the case of inspection by using range data (images 3D).

For tolerance checking, many workers [19,20] report inspection systems using intensity images (images 2D). Some inspection systems use information provided by a CMM [21–23]. Roy [24] developed a methodology for computer-assisted geometrical tolerance checking, incorporated in a CAD system.

A tolerance is a specification, which defines the acceptable variation of dimension or geometry of an element. According to the field considered, two types of tolerance are usually used:

– Dimensional and angular tolerances.
– Geometrical tolerances.

In this section, we will describe the methodology used for the control of these two kinds of tolerance.

Since the registration process minimises the square of the sum of the distances between the 3D points and the CAD model, the set of those distances will have a Gaussian distribution [25].

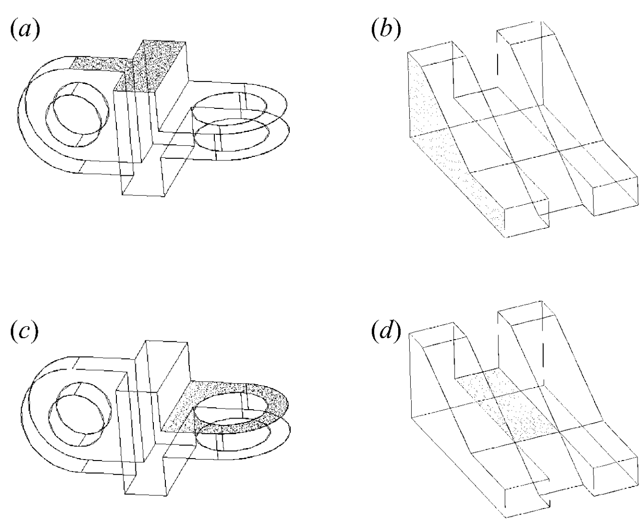

Fig. 1. Segmentation of surfaces from a cloud of 3D points registered with the CAD model of the part. (*a*) Surface 1 of part two. (*b*) Surface 2 of part one. (*c*) Surface 12 of part two. (*d*) Surface 7 of part one.

4.1 Dimensional Tolerances

The dimensional tolerances are expressed as the difference between the high and the low size limits of a toleranced dimension. This represents the interval in which the effective dimension of an element can vary. Figure 2 shows some dimensional and angular tolerances which were specified for a part.

4.2 Dimensional Tolerances Checking

We can control dimensional tolerances corresponding to the dimensions between two parallel surfaces, like that shown in Fig. 2.

Figure 3 shows the process used for the dimensional and angular tolerance checking. Dimensional tolerance checking is illustrated in Fig. 3(*a*). For the subsets of points related to parallel surfaces which define the dimension to be controlled, we compute the distance between each point and the nearest surface to determine the values d and σ. The measured dimension is thus $d_0 \pm 2(\sigma_1 + \sigma_2)$, where d_0 is the distance between d_1 and d_2.

Let $d_s \pm \Delta d_s$ be the specified dimension for the surface under control, we can say that the surface conforms to its specifications if the following conditions are satisfied:

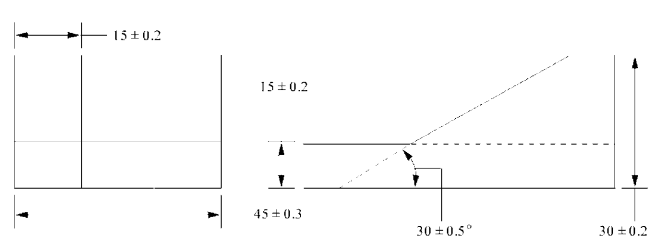

Fig. 2. Dimensional and angular tolerance specifications of a part.

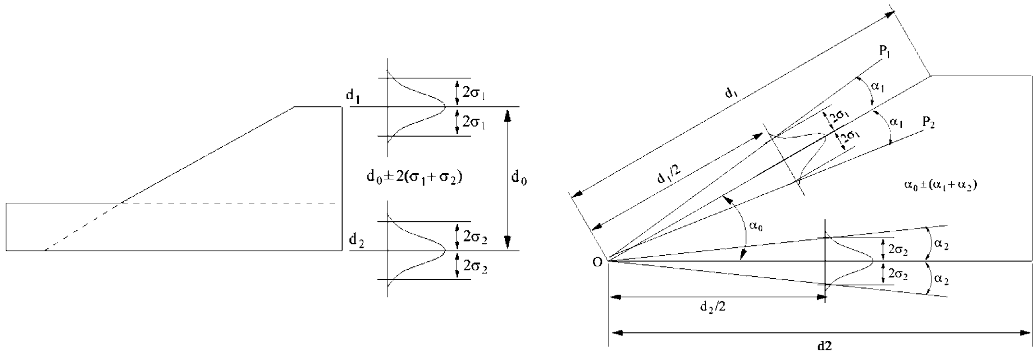

Fig. 3. Process for (*a*) dimensional and (*b*) angular tolerance checking.

$$d_s - \Delta d_s \leq d_0 - 2(\sigma_1 + \sigma_2)$$
$$d_0 + 2(\sigma_1 + \sigma_2) \leq d_s + \Delta d_s \quad (1)$$

4.3 Angular Tolerance

This is the difference between the maximum and the minimum opening of a toleranced angle. It represents the interval inside which the opening of an angle can vary. Figure 2 illustrates an angular tolerance.

4.4 Angular Tolerance Checking

We illustrate in Fig. 3(*b*) the method used to control the angular tolerances. We determine the values $\bar{d}$ and σ for the subsets of points related to surfaces which define the angle to be controlled. Let P_1 (P_2) be the plane which passes by the line O (line defined by the intersection of the planes which form the angle under control) and by a point located at a perpendicular distance of 2σ (-2σ) from the centre of the surface. The angle α_1 is the angle formed by the plane $P_1(P_2)$ and the NURBS surface. The angle α_2 is estimated by a similar procedure. The measured angle is thus $\alpha_0 \pm (\alpha_1 + \alpha_2)$, where α_0 is the angle formed by the two surfaces.

Let $\alpha_s \pm \Delta\alpha_s$ be the specified angle. We say that the specification is met if the following conditions hold:

$$\alpha_s - \Delta\alpha_s \leq \alpha_0 - (\alpha_1 + \alpha_2)$$
$$\alpha_0 + (\alpha_1 + \alpha_2) \leq \alpha_s + \Delta\alpha_s \quad (2)$$

4.5 Geometrical Tolerances

The geometrical tolerance is the maximum acceptable interval into which the geometrical characteristics of form, orientation or position of an element can vary.

4.5.1 Form Tolerance

This is the maximum deviation allowed to the form of an element. According to the geometry of the element, the tolerance zone is limited by two surfaces, distant by t_s and between which the considered surface must be located. A form tolerance applies only to the shape of the toleranced element independently of its environment, position or orientation. Flatness, straightness, cylindricity and profile of a surface are some of the form tolerances. Figure 4 illustrates the planes which limit a surface under control (accentuated line), those are not attached to the surface of reference *A*.

4.5.2 Orientation Tolerance

It is the maximum deviation allowed for the orientation of an element related to a reference element. The tolerance zone is limited by two planes or a cylinder inside which the considered surface must be located. The tolerance zone is mobile in translation and does not determine or control the position of the element. Angularity, perpendicularity, and parallelism are examples of orientation tolerances.

Figure 4 shows the planes which limit a surface under control, those planes have the same orientation as the reference surface (datum surface) *A*, but are not limited to the datum/surface distance.

4.5.3 Location Tolerance

This is the maximum deviation allowed for the location of an element. The tolerance zone is limited by two planes, a parallelepiped or a cylinder inside of which the considered surface must be located. The tolerance zone must be directed and located according to one or more elements of reference. Figure 4 illustrates the planes which limit a surface under control, the orientation and the position of those are attached to the reference surface *A*.

Figure 5 illustrates some geometrical tolerances which were specified for a industrial part.

4.6 Geometrical Tolerances Checking

4.6.1 Form Tolerances Checking

According to the definition of form tolerances, we know that they limit neither the orientation nor the position of the surface, and that they are applied directly to the surface under control without considering a datum surface. Thus, we check form tolerances of a surface by using only the 3D points associated with this surface and obtained from the segmentation process. This subset of 3D points is registered with the CAD model, and the perpendicular distance between each 3D point and the

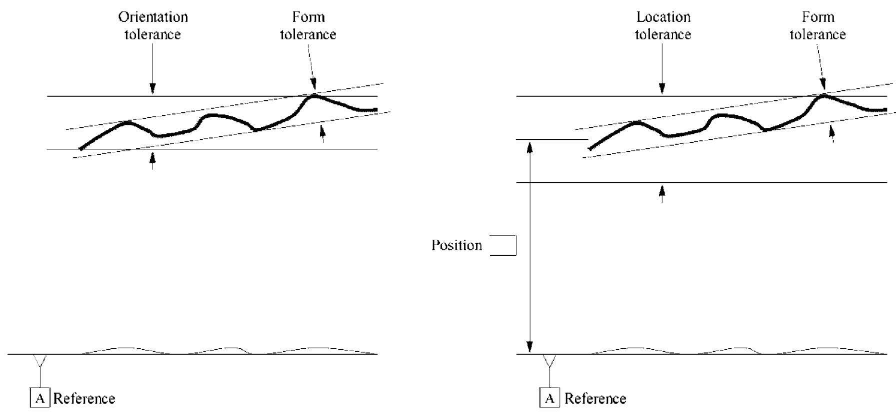

Fig. 4. Geometrical tolerances of form, orientation, and location.

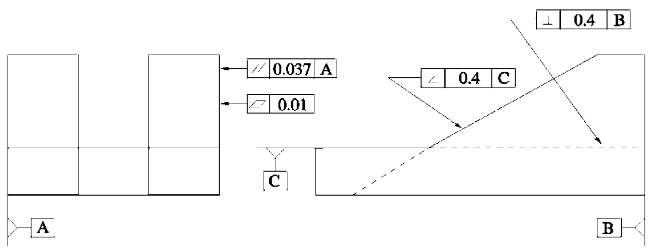

Fig. 5. Specification of geometrical tolerances for a part.

NURBS surfaces is calculated. The distribution of these distances is used to define the zone of measured tolerance. We adjust the average value of the distribution with the NURBS surface (of the CAD model). We place two parallel surfaces to the NURBS surface at a distance $\pm 2\sigma$, then the measured tolerance is $t_m = 4\sigma$. For the flatness tolerance, these surfaces are planes whereas for the cylindricity tolerance, these are cylinders of different radii. In Fig. 6, we show the control of a flatness tolerance. In this figure (and those following), the accentuated line represents the cloud of 3D points after registration.

Parts with complex forms include curved surfaces and a relatively few flat surfaces. The only geometrical tolerances specified for this type of surface are the profile tolerance of any surface, which are tolerances not easily controllable by traditional techniques of metrology. On the other hand, by

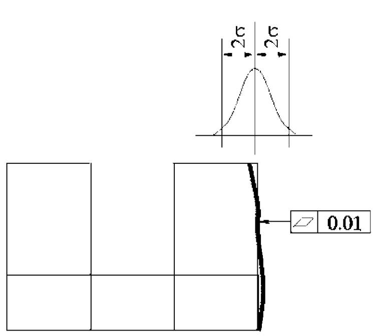

Fig. 6. Form tolerances checking: flatness.

using a methodology like that presented in this work, we can control these types of tolerance.

The tolerance zone of a profile tolerance of any surface is limited by two surfaces limiting the spheres of diameter t whose centres are located on a surface having the specified geometrical form. For the control of these tolerances, we use a NURBS surface as the specified surface, and the diameter of the spheres, which defines the tolerance zone, is $t_m = 4\sigma$.

For form tolerances, we say that surface is in conformity with the specification if the following relation is satisfied:

$$t_m \leq t_s \tag{3}$$

where t_m is the measured distance between the parallel planes and t_s is the specified tolerance.

4.6.2 Orientation Tolerances Checking

Orientation tolerances limit the form and the orientation of a surface but do not limit the position. To define the orientation, these tolerances are always related to a datum surface. Consequently, we must use two subsets of points: S_i associated to the surface to be inspected and S_r associated to the reference surface. The subset S_r is registered with the CAD model and the computed rigid transformation is also applied to S_i. The perpendicular distance between each 3D point of S_i and the NURBS surface is calculated. The distribution of these distances does not have a Gaussian form, and thus two points are defined in order to evaluate the zone of the measured tolerance: the point p_1 at a distance d_1 from the NURBS surface such that 2.5% of the points in S_i have a distance $d_i \leq d_1$, and the point p_2 at a distance d_2 from the NURBS surface such that 2.5% of the points in S_i have a distance $d_i \geq d_2$. The zone of measured tolerance is then defined as the range between two parallel planes with an orientation related to the reference surface and passing through the points p_1 and p_2.

For orientation tolerances, the inspected surface is in conformity with the specification t_s if the following relation is satisfied:

$$t_m = |d_2 - d_1| \leq t_s \tag{4}$$

Figure 7 illustrates the control of some tolerances of orientation.

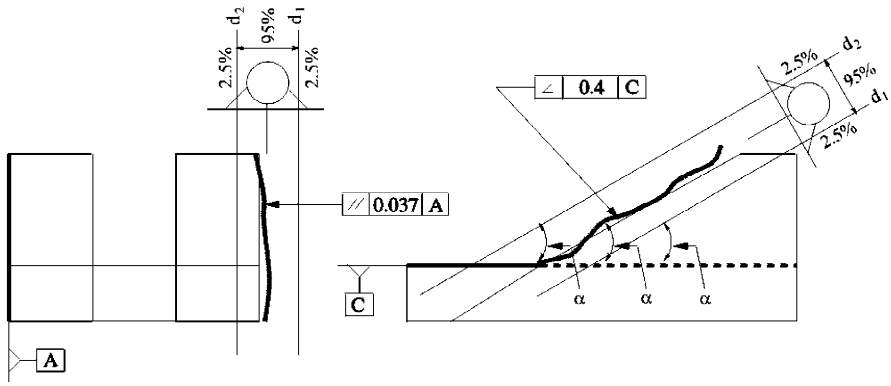

Fig. 7. Orientation tolerances checking.

4.6.3 Location Tolerances Checking

This is the maximum deviation allowed for the location of an element. Two planes, a parallelepiped or a cylinder limit the tolerance zone where the surface considered must be located. The tolerance zone must be directed and located according to one or more elements of reference.

The location tolerances are controlled similarly to the tolerances of orientation. To ensure the conformity of the surface under inspection, the following relation must be satisfied:

$$t_{1_s} \leq t_{1_m} < t_{2_m} \leq t_{2_s} \tag{5}$$

where t_{1_s} and t_{s_s} are the distances from the surfaces which define the tolerance zone specified to the reference, and t_{1_m} and t_{2_m} are the distances from the surfaces which define the tolerance zone measured to the real reference (S_r).

5. Results

After the digitisation of a part, the resulting cloud of 3D points is registered with its CAD model and then segmented according to its surfaces. These subsets of 3D points are thus used for the tolerance checking of the part. For a rapid visualisation of defects in the part, we implemented a graphical user interface. Once the segmentation is carried out, we can thus choose the surface of interest and perform its tolerance inspection.
We describe below the different actions that can be executed starting from this graphical user interface:

1. *Interval of tolerance.* This allows us to fix the minimum and maximum tolerances between which the points of the surface must lie in order to decide whether the surface is in conformity with the tolerance specifications.
2. *Threshold value.* This allows us to choose a threshold value either positive (maximum of matter), or negative (minimum of matter), and to visualise, after computation and display of the points with different colours, the zones where there is too much material or not enough.
3. *Display of linear segments.* This allows a better visualisation of the two preceding actions, to display not a point but a linear segment connecting the 3D point to the surface.

We present some results in Fig. 8 obtained with the graphical user interface. Figure 8(*a*) illustrates the result obtained when the option *tolerance interval* is selected. The values of tolerance can be modified and the system displays the points within the new interval of tolerance with different colours compared to those located out of the interval. In the example of Fig. 8(*a*), the interval of tolerance is (–0.6214 mm, 0.4128 mm). Choosing the option *threshold value*, we can indicate a threshold value and the system displays the points having a distance greater than the threshold with a colour different from those with a smaller distance. For example, in Fig. 8(*b*) the threshold is 0.3 mm. The results of the previous options can be displayed as linear segments between each 3D point and their nearest point on the surface, when the option *display of linear segments* is selected. By using this option we can better visualise certain defects on the part, such as those illustrated in Figs 8(*c*) and 8(*d*).

5.1 Tolerance Inspection

We show some results from the inspection of tolerances. The specified tolerances that we will control are:

Dimensional tolerance between two parallel surfaces whose specification is 45 ± 0.3 mm.

Flatness tolerance on a surface of the part *one* with a specification of 0.01 mm.

Perpendicularity tolerance on a surface compared to a datum surface *A* with a specified value of 0.4 mm.

Angularity tolerance on a surface connected with the datum surface *B* with a specification of 0.4 mm.

Profile tolerance of any surface of part *two* with a specification of 0.04 mm.

For the inspection of these tolerances, the parts were digitised with a Biris range sensor and an autosynchronised range sensor, developed at the National Research Council of Canada [26,27].

In the examples of tolerance checking presented, there are dimensional and geometrical tolerances of form and orientation. Other tolerances can be verified in a similar way.

5.1.1 Inspection Using Data from a CMM

In order to establish the exact deviations of the geometrical characteristics that we inspect, we carried out the control by using a CMM with an accuracy of 5 μm. We show the results

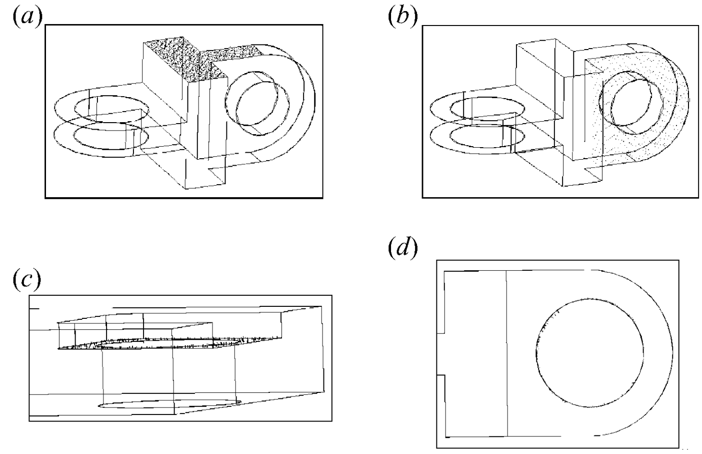

Fig. 8. Rapid visualisation of defects in a part by using a graphical user interface. Selection of the option: (*a*) interval of tolerance, (*b*) threshold value, (*c*) display of linear segments, (*d*) display of linear segments.

Table 1. Tolerance inspection using a CMM.

Tolerance name	Specified value (μm)	Measured value (μm)	Result
Dimensional	45 000 ± 300	45 016 ± 1	Conform
Flatness	10	10.8	Not-conform
Perpendicularity	400	39	Conform
Angularity	400	26	Conform
Profile	40	10.3	Conform

in Table 1, where we present the tolerance under control, the value of specified tolerance (t_s), the value of measured tolerance (t_m) and the inspection result. Tolerances under control are: Dimensional tolerance, Flatness tolerance, Perpendicularity tolerance, Angularity tolerance and Profile tolerance.

The results show that except for the geometrical tolerance of flatness, all the controlled tolerances are in conformity with their specifications. The measured value column shows that the tolerance values lie between 1 μm and 39 μm.

5.1.2 Inspection Using 3D Data from the Biris Range Sensor

We illustrate in Table 2 the results of control by using the cloud of 3D points resulting from the part digitisation with the Biris range sensor. The inspection results show that the dimensional tolerance and the tolerances of perpendicularity and angularity are in conformity with the specified value, whereas the tolerances of flatness and profile of any surface are not in conformity with their specifications.

According to the value of specified tolerance, we note that the tolerances found in conformity are those which have a specification higher than or equal to 300 μm. The measured values of tolerance lie between 146 μm and 299 μm with an average value of 216 μm. For this set of tolerances, the average value obtained with the CMM is 18 μm. Consequently, an estimate of the size of the tolerances that we can control with the Biris sensor is that of all the tolerances whose specifications are higher than or equal to about 200 μm.

5.1.3 Inspection Using 3D Data from the Autosynchronised Range Sensor

The results of the tolerance checking by using the cloud of 3D points resulting from the digitisation with the autosynchronised range sensor are shown in Table 3. Inspection results are similar to those obtained for the inspection with the 3D data from the Biris range sensor. On the other hand, the measured values of tolerances lie between 41 μm and 174 μm with an average value of 92 μm. So, for 3D data coming from the digitisation with the autosynchronised range sensor, we estimate that tolerances whose specifications are higher than or equal to 100 μm can be controlled.

Finally, we show, in Table 4, the number of 3D points used for the tolerances control, for each of the three processes

Table 2. Tolerance inspection using 3D data coming from the Biris range sensor.

Tolerance name	Specified value (μm)	Measured value (μm)	Result
Dimensional	45 000 ± 300	45 006 ± 140	Conform
Flatness	10	146	Not-conform
Perpendicularity	400	267	Conform
Angularity	400	299	Conform
Profile	40	230	Not-conform

Table 3. Inspection using 3D data coming from the auto-synchronised range sensor.

Tolerance name	Specified value (μm)	Measured value (μm)	Result
Dimensional	45 000 ± 300	44 993 ± 38	Conform
Flatness	10	72	Not-conform
Perpendicularity	400	134	Conform
Angularity	400	41	Conform
Profile	40	174	Not-conform

Table 4. Number of 3D points used for the tolerance control.

Tolerance name	CMM	Biris	Autosynised range sensor
Dimensional	25	1774	2321
Flatness	20	888	1467
Perpendicularity	29	1680	2166
Angularity	32	2625	1745
Profile of any surface	16	146	638

(CMM, Biris range sensor, and autosynchronised range sensor). In general, this number is higher than 1000 points on surfaces, distributed uniformly over the whole surface. This characteristic of the method is very interesting. In the inspection with a contact sensor like a CMM it is impossible to acquire a similar number of points since that would require several working hours to digitise just one surface.

A problem with the range sensors is apparent when we want to measure an inner surface, on which it is much more difficult to have a large number of points. That is due to occlusion problems or to the high incidence angle between the beam and the surface. Actually, accuracy of the 3D points is dependent on the point of view at the time of digitisation. For this reason, we have used only 95% of the points (4σ). It is for this reason, too, that it is more certain that we will have a good result when we find a surface conforms to its tolerance specification, rather than the opposite case.

In addition, since the inspection consists of checking the precision of a manufactured part compared to its specifications, it is necessary for the inspection method to be very precise. At the time of the digitalisation of a part by a range sensor, several sources of error can modify the measured points. A remaining problem is defining the accuracy range with which we can affirm that a part conforms to its tolerances specifications when we use the measurements from a range sensor.

6. Conclusion

We have presented an inspection system for manufactured parts. We have defined and implemented a methodology to check geometric tolerances, using a cloud of 3D points and a CAD model of the part. The system first registers a cloud of 3D points with a CAD model of the part, then segments the 3D points on different surfaces by using the CAD model, and finally controls the specified tolerances on the part.

The inspection methodology presented allows us to verify tolerances not only on flat surfaces but also on complex surfaces, because we know the exact description of the part from the CAD model.

Inspection results are displayed in two ways: visually, using a colour map to display the discrepancy between the measured points and the CAD model; and a hardcopy report of the evaluation results of the tolerance specifications. The methodology was used with two range sensors, and inspection results were compared to the results obtained with a CMM, and it is shown that, in general, the results are similar.

The precision in the inspection results is mainly a function of the precision of the 3D points. At present we can find some range sensors with a high precision, but in order to approach the precision of a coordinate measuring machine much work has to be done during the digitisation process. In spite of this precision problem, range sensors are very interesting in the inspection task because they provide a large number of measurements in a short period of time and without contact with the part.

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