Non-contact whole-part inspection

Gabor Lukacs, John Lockhart, Mike Facello

Geomagic, Inc.

Gabor Lukacs, Geomagic, Inc., PO Box 12219, Research Triangle Park, NC 27709, Phone: 919-474-0133, glukacs@geomagic.com

Abstract

Recent advances in optical scanning devices enable us to collect millions of sample points of reasonable individual accuracy on a part to be inspected. There are obvious advantages of non-contact inspection methods: speed, coverage, ease of operation, price, etc. One may ask why non-contact methods are not even more widespread in dimensional measurement. In fact the automatic extraction of actual dimensional and GD&T values from non-contact measurement data is not an easily repeatable and reproducible procedure. What is the reason for this?

Certainly there are major differences between CMM and non-contact measurement data that require sometimes fundamentally different approaches. The first difference is that the *accuracy* of the individual points in non-contact measurements is usually inferior to that of touch-probe devices. This problem has traditionally caused considerable concern; however, these doubts can be less and less sustained as the overall accuracy of the devices improve. The second difference is that some surfaces, due to glossiness or transparency, are not *suitable* for optical measurement and cause special errors. This is a valid argument but at the same time there are many materials that are inadequate for touch-probe measurement as well (e.g. soft or flexible substances). There is a third difference: the sheer *amount of the collected data*. This might be of the most significance, at the same time a blessing and a curse for non-contact measurement. The vast amount of points provides far more coverage, but the inspector must relinquish his/her individual control over the individual points. So this difference is more in the process of assessment than in the geometric algorithms. In some way this difference forces the engineer to think about dimensional inspection and GD&T in a somewhat different way. The main emerging concepts are the automatic classification of measured points with respect to the features to be measured and the automatic elimination of outliers. Using these concepts Geomagic developed special solutions to deal with large collections measurement data in an automatic and semi-automatic way. This paper will introduce some of these ideas and methods.

Introduction

Optical non-contact inspection techniques have revolutionized inspection applications in the last decade. The cost and coverage of these devices made these techniques attractive in a number of situations. Laser and structured white light scanner devices are being used more and more in many situations of manufacturing. In many areas of medium and large scale manufacturing processes, scanning devices with the related inspection software will become the primary tools of inspection in the industry.

Touch probe (tactile) CMM measurement machines have been used successfully since the sixties of the last century. The seventies brought a revolution of high precision CMM devices mostly by the advance of Japanese machine tool industry and metrology companies. These devices are reliable and highly accurate instruments, their precision (repositioning accuracy) lies in sub micrometer range.

Laser white light, and computed tomography scanners have a somewhat shorter history. The first reliable devices are from the mid nineties. The most accurate devices are able to report coordinates reliably in the micrometer range, but taking into account the internal registration procedures, the accuracy of the individual points are usually over ten or twenty micrometers.

Computer tomographic (CT) scanners have recently been adopted for inspection purposes. These instruments were first used in medical applications. From the mid eighties there have been attempts to employ 2D and spiral CT devices in metrology, but the real breakthrough is expected from the use of cone-beam CT scanners. These devices have been around since the early 2000. They seem to be particularly suitable for injection-molded plastic parts, which have many internal features. Macro–3D scanners provide the accuracy around the size of the voxel size of the device, currently around two to four hundred micrometers.

CMM software followed the footsteps of numerically controlled machine tool programming. It has become more and more sophisticated to approach, touch and follow surfaces from different directions. For the right alignment of the part complex fixtures and gauges have been designed and modeled in the programming system.

Non-contact measurement software had to take a different route. Instead of single points the basic information is a set of range images (possibly unregistered) or more directly unordered point clouds or polygon meshes. Consequently scanner software has built on Computer Vision software, Discrete Computational Geometry, and CAD.

These are not just algorithmic differences, but in many ways that of different culture. The CMM approach is usually quite adequate if we have sufficient a priori knowledge about the feature we want to inspect and the actual feature does not deviate too much from the nominal one. It is much less appropriate if it has free-form geometry or the deviation is large. Additionally, automatic evaluation algorithms of non-contact measurement results require special care in identification of the respective points of features.

This paper presents techniques that help to bridge the divide between the feature targeted analytical CMM methods and the comprehensive algorithms characteristic to non-contact inspection algorithms.

Related Work

The general performance of CMMs has been the subject of very extensive research and standardization. The work was performed mostly in the nineties [1, 2, 3, 4, 5].

Despite the wide availability of non-contact inspection systems, there are few exhaustive evaluation studies. [6] refers to most organizations dealing with these issues. The comprehensive nature of scanning data calls naturally for automatic whole-part inspection algorithms. The solutions offered by software such as Geomagic Qualify (e.g. [7]) provide practical methods for tolerance specifications which can be verified once a reasonably full, usually scanned, inspection data of the as-built object is available. These kinds of solutions have been on the market since approximately 2000, but since the early versions the inspection functionalities of these solutions have developed immensely. The Geometrical Product Specification standards of ISO (ISO/TS 17450) point in a similar direction [8,9]. The approach presented in [10] and [11] describes the whole-part inspection process as a fully automated process that is based on the toleranced CAD model of the part. The inspection of free-form surfaces often poses similar problems (see e.g. [12]) that the users of non-contact inspection software can solve in a successful way.

The software solutions, like Geomagic Qualify are in many ways products of synthesis of algorithmic efforts in various fields of computer science: 3D computer vision [13], discrete computational geometry [14, 15], and reverse engineering in computer-aided geometric design [16]. The main achievement is the integration of algorithms and methods from all these fields in order to obtain a solution for the whole-part inspection problem.

Tactile and non-contact - Segmentation

Considering the usage of CMM based inspection by touch probes and the non-contact optical scanning by laser or structured white light, the prime technical questions are that of accuracy, material and form sensitivity, along with the quantity of data. Without doubt there are other important questions, first of all the expense of one or other solution means, the physical dimensional constraints of the device, the expertise required to use one or the other solution, the traditions of the given industry, and the local standards of the given manufacturing plant.

Concentrating on the more technical issues, the accuracy of CMM is still roughly one or two decimal order higher than that of non-contact measurements -- around 0.1 micrometers of touch probes vs. laser 5-10 micrometers of scanners [17, 18]. Registration may add further uncertainty; however, recently used photogrammetric techniques improve registration accuracy significantly. For CMM the materials should be hard enough to resist probe force and in case of non-contact scanners the reflectivity and color of the surface may cause problems. In both cases the surfaces should be able to be approached appropriately with kinematics of the probe and in case of a scanning device it should be able to be exposed to an optical beam.

Still the main difference is the amount and the “destination” of the collected data. For touch probes the collected points are controlled directly or indirectly (through a program) by the human operator. The number of points is up to a couple of thousands and they clearly belong to a single feature. For scanning the number of points collected is from several hundred thousand into the millions and the system has no a priori knowledge on which surface or feature the collected points reside. This circumstance leads us to the fundamental issue that distinguishes tactile and non-contact data collection, including CT [19, 20]. Probably the main barrier in the usage of non-contact methods is the difference in the automatic classification (segmentation) of data. In fact this is very much like the fundamental problem in computer vision [13, 21]. The main question is which point of measured data belongs to which feature of the reference model. This is clearly a problem that does not exist in the traditional probe based CMM inspection, since the classification is determined explicitly by the human operator.

Comprehensive solution: Correspondence

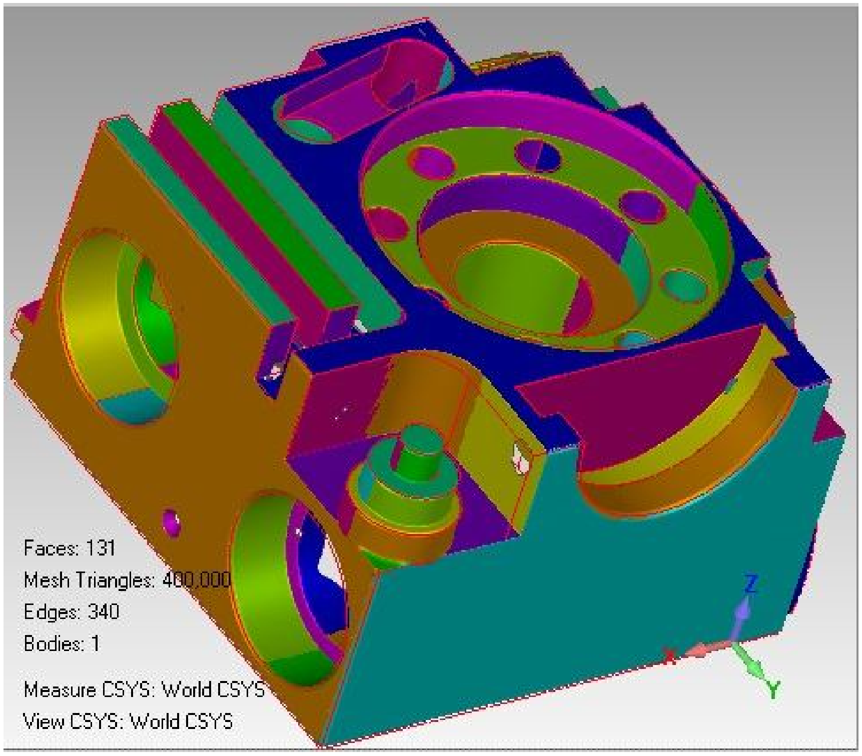
The nature of non-contact data poses some typical difficulties to overcome:

- The raw data frequently contains outliers, special reflection artifacts.
- In many cases it is uncertain whether given points belong to a feature or to one of its neighboring features. It is an especially hard problem if there is no clear-cut geometric boundary between the two areas.

We have introduced an explicit data structure that describes the classification of the measured data of the complete test object. The classes belong to individual features (in most cases CAD faces) of the CAD reference object.

The main idea is that this classification can be used throughout the whole inspection process, since:

- Each feature (or CAD face) uniquely determines the class of measured points (or triangular facets on a polygonal mesh test data). This set does not depend on whether the feature is used as a datum, for defining alignments in a feature control frame, as a considered feature in a given inspection query, or possibly in sections for planar dimensioning or profiles.
- The classification does not depend on any particular alignment between the reference and the test model. This means that the classification depends fundamentally on the internal geometry and topology of the two models.

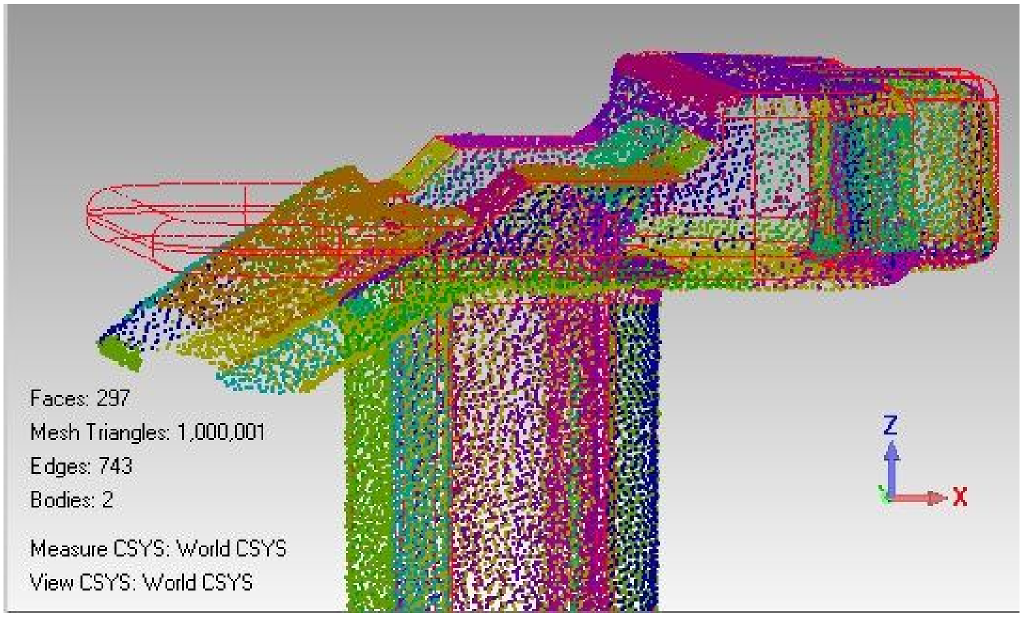


Mathematically the correspondence is a mapping that assigns a set of points to every feature on the reference object. Correspondence expresses the topological relationship between the nominal and measured data. Figuratively if the nominal features are basic words by which the inspection directives are described, then the correspondence is the tool that translates these basic words to the language of the actual features.

Algorithmic questions

The key issue is the algorithm that generates the partition of the test data based on the geometric model of the reference object. This is obviously a complex algorithm and there are many attempts in reverse engineering of CAD surface topology to deal with similar problems [16, 22, 23, 24, 25, 26]. The main difference of the correspondence algorithm with respect to these approaches is that the segmentation should follow the template of the CAD reference model.

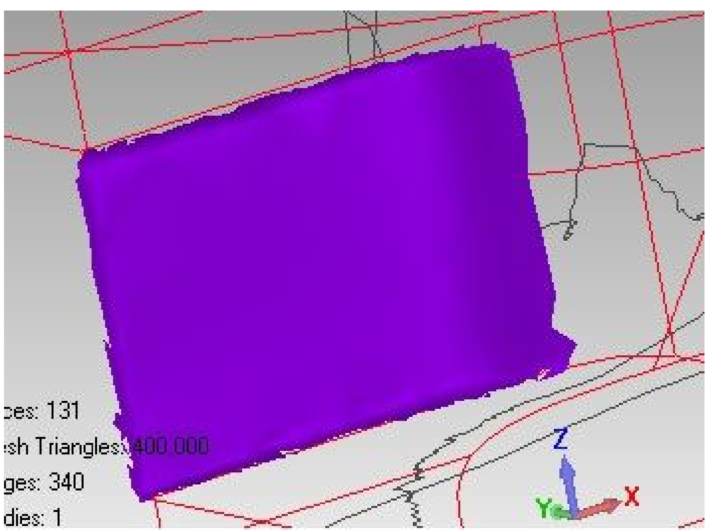
The correspondence algorithm starts from some hypothetical alignment in order to match the features of the reference model to subsets of the test object. This alignment is used only for finding initial areas of the segmentation, later these regions will be grown and refined according to the inner geometry of the object. In fact the proximity itself will not determine to which class a given area should be classified as the following picture illustrates:



The correspondence algorithm applies an intelligent search based on the normal approximation of the test data. The algorithm utilizes topological and geometric classification techniques that were first developed in the functional decomposition approach [13,16].

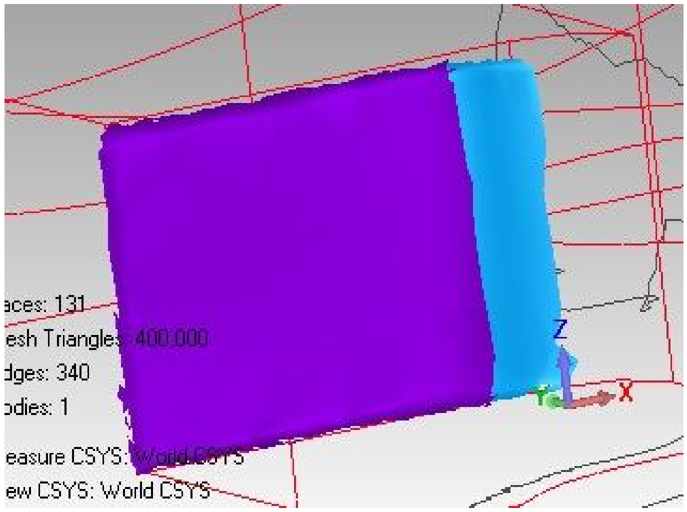
Editing

Once the correspondence mapping is created for a given test object, the interactive editing of the



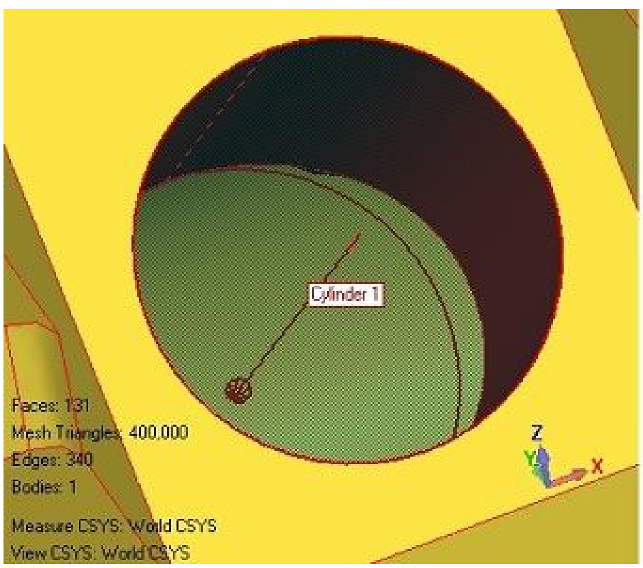
components might be advantageous.

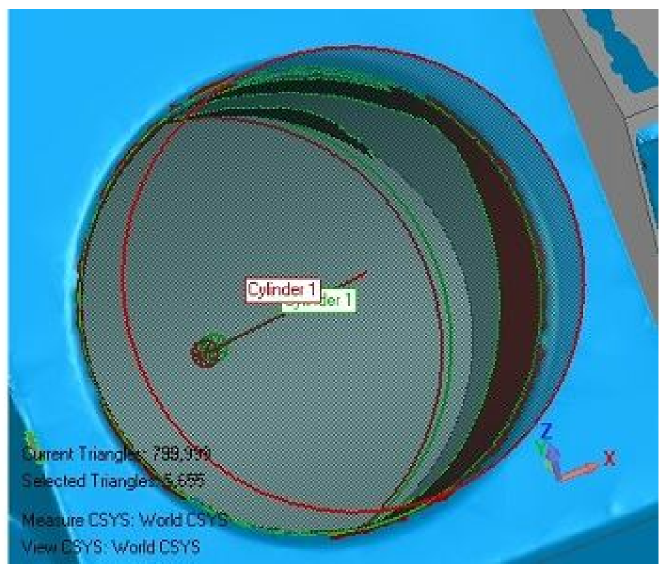
This can be useful if the boundaries of the segmented areas are to be corrected. It is possible to shrink the area or to subtract or add points around the boundary. In the following picture one can see the effect of the editing.



Usage

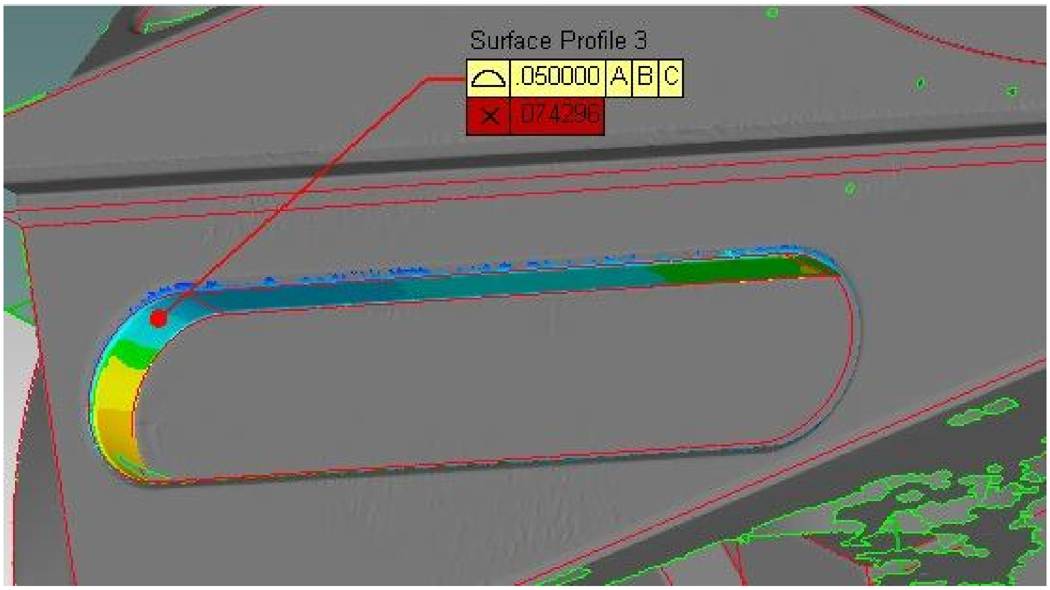
Correspondence enables the system to create the actual version of a feature on the test object automatically. The term “auto-creation” of features is used for this process.





When activating this procedure the subset of the measured data is retrieved that corresponds to the reference feature and a fitting algorithm is performed to create a feature attached to the test object.

Once a set of suitable features is created, a feature based alignment can be performed that aligns the test object to the frame of the reference model. With the appropriate constraints, this kind of alignment can be used in evaluation of GD&T callouts and tolerances. A result of such an evaluation can be seen in the following picture.



Summarily the usage of the correspondence mapping enables the total automation of the inspection process. Once we have the reference CAD model together with inspection directives (possibly in the form of PMI information) and the suitable non-contact (scanned) measured data of the part is available, then the full inspection report can be obtained in a fully automatic way.

Conclusion

The difference between the analysis algorithms of tactile and non-contact inspection data has been discussed, and a solution offered by Geomagic has been described. The correspondence mapping explicitly connects the topological structure defined by the features of the reference data to the collected data of the test geometry. By means of this tool the dependency of analysis algorithms on the particular measurement data collection method can be removed and the inspection process can be fully automated.

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