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Quality Control of Quick Response Products by Used of Reverse Engineering Technologies

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Abstract: Error comparisons of fabricated parts and original CAD design is often a difficult yet important issue in product quality control. In this study, an integrated technique of 3D scanning with reverse engineering and rapid prototyping technologies proposed. This will be applied to the entire quality control phase of quick response products during the manufacturing process. For evaluation of presented approach, an automotive test model was made using the layered manufacturing process RP fabricator, a 3D Printing RP system. Then non-contact laser 3D scanner with RE software employed to evaluate dimensional deviations of manufactured RP model. Regarding to the result of inspection, maximum deviation was −0.306 mm. So, with the virtue of the 3D laser scanning system and RE software, the proposed method could be used during the entire quality control phase of the manufacturing process.

Key words: Rapid prototyping, reverse engineering, 3D scanning

INTRODUCTION

Global competition, customer-driven product customization, accelerated product obsolescence and continued demands for cost saving are forcing companies to look for new technologies to improve their business processes and speedup the product development cycle (Pham and Dimov, 2001). To be agile and lean, companies cannot apply traditional approaches that often result in problems with inventories, overhead and inefficiencies. Companies need to create small quantities of highly customized, designed-to-order parts that meet the needs of the global customer. The swift trend toward a multiplicity of finished products with short development and production lead times has led many companies into problems with inventories, overhead and inefficiencies. They are trying to apply the traditional mass-production approach without realizing that the whole environment has changed. Mass production does not apply to products where the customers require small quantities of highly custom, designed-to-order products and where additional services and value-added benefits such as product upgrades and future reconfigurations are as important as the product itself.

Recently, the fashion of outlook and profile design for new products has become more streamlined in shape, or arc shaped. It is a challenge for conventional manufacturing processes to fabricate such products quickly and cost-effectively. As the technology matures, Reverse Engineering (RE), Rapid Prototyping (RP) and Rapid Tooling (RT) draw a lot of attention from manufacturers. RE/RP/RT are also known as 3R technologies. 3R applications are likely to be extended into many other areas. The 3R technologies provide a means by which three dimensional data can be captured in digital form from physical models or samples. It has obvious attributes in terms of shortening the design-to-market process and effective use in conjunction with other time compression technologies, such as CAD/CAM/CAE.

In order to assure the dimensional accuracy of molds or products, quick error comparisons of fabricated parts and an original CAD design is often a difficult yet important quality control issue in product manufacturing processes.

The reduction of the product development time, therefore, requires revolutionary improvements rather than gradual changes in technology. In this way, many studies have been done on effective utilization of reverse engineering technologies for rapid product development and quality control. Yen *et al*. (2005) implemented a study on error analysis of NC machined free-form surfaces in RE. Also, some researchers focused on relationship between reverse engineering and rapid prototyping and developed some different approaches for direct of RE and RP (Kumbhar *et al*., 2008; Zhongwei, 2004; Liu *et al*., 2003; Chen and Ng, 1997).

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In this study, an integrated technique of 3D laser scanning, RE and RP technologies for the entire quality control phase of quick response products during the manufacturing process presented. A powder type 3D Printing system and non-contact laser 3D scanner with RE software are employed in this study. The proposed technique is able to provide a means by which the accuracy of fabricated parts can be examined and analyzed quickly.

MATERIALS AND METHODS

The experimental setup and procedures are shown in Fig. 1. An automotive part was designed with CAD software as a test part. The CAD design data is shown in Fig. 2. Then a powder type 3D Printing machine used to produce this part for measuring by a 3D scanning system.

The goal of this study is aimed at establishing a procedure for total quality control by using the integrated 3D scanner, RE software and RP technologies. The proposed flow chart of experimental procedures is as follows: test models were designed in CAD software (e.g., solidworks), RP prototypes were then made by a 3D printing RP system based on CAD design data of the models, the RP prototypes were then measured and examined by 3D scanner and RE software.

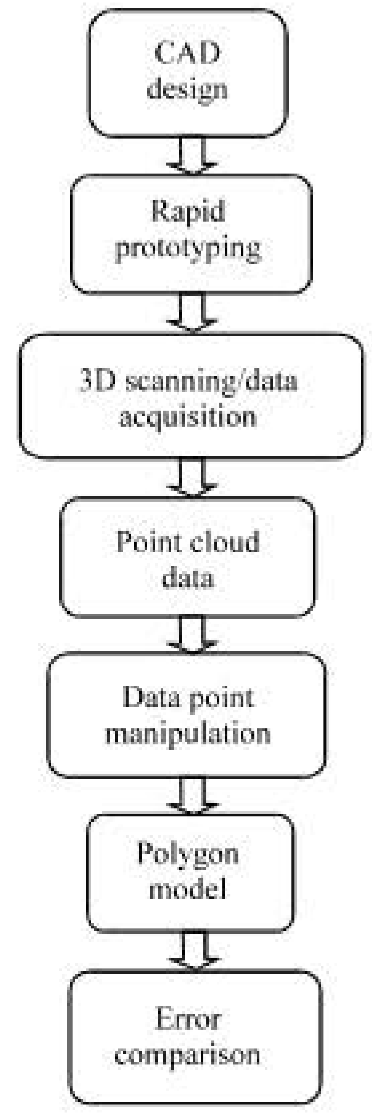

Fig. 1: Proposed flowchart for experiment

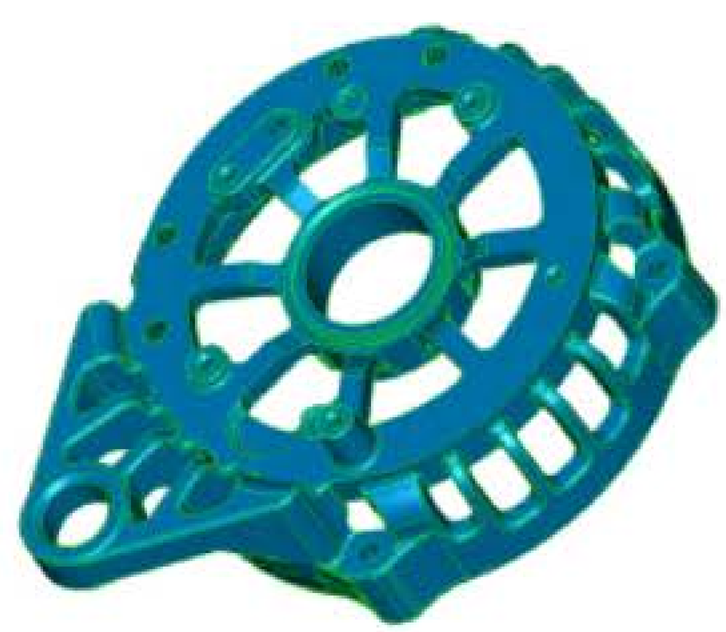

Fig. 2: The CAD design of test automotive part

Rapid prototyping: The term rapid prototyping refers to a class of technologies that are used to produce physical objects layer-by-layer directly from Computer-Aided Design (CAD) data. RP techniques are fast becoming standard tools in product design and manufacturing. With revolutionary capabilities to rapidly fabricate three-dimensional parts for design verification or to serve as functional prototypes and production tooling, RP is an indispensable tool for shortening product design and development time cycles (Raja and Fernandes, 2007; Chua and Leong, 1998; Cheah *et al*., 2005). RP procedures do not require planning during the process, specific equipment for work with materials, transport between workplaces, etc. However, compared with CNC processing, the main drawback of these processes is that they are currently limited to fewer materials (Pilipovic *et al*., 2009). There are various methods of rapid prototyping. One of the most effective RP techniques is three dimensional printing (3D Printing). The 3D Printing technology was developed at the Massachusetts Institute of Technology (MIT). Basically, the 3D Printing is a layered fabrication process, in which the sliced 2D profile of a computer model is printed on a fresh layer of powder via., deposition of a suitable binder. Successive 2D profiles are then printed on a freshly laid layer of powder until the whole model is completed. The printed binder would join the respective profiles of each layer together. The part is completed upon removal of the unbound powder and suitable post-processing. 3D Printing is a unique technique that prints complex 3D structures that cannot be produced by other means, especially for rapid prototype purpose (Sachs *et al*., 1992; Yin *et al*., 2007; Seitz *et al*., 2005). To increase strength and durability, the part can then be infiltrated with wax, epoxy or other materials. 3D Printing has demonstrated the capability of fabricating parts of a variety of materials, including ceramics, metals and polymers with an array of unique geometries (Seitz *et al*., 2005; Cawley, 1999).

Fig. 3: The produced model of test part by 3D printing process

In present study, the designed automotive part made by 3D Printing procedures on the ZCorp.'s Z510/Cx 3D Printer apparatus. ZCorp. uses inkjet print heads with a resolution of 600 dpi (dots per inch), focuses on a drop-on-demand approach. ZCorp. first introduced high-resolution 3D Printing (HD3DP) in 2005. The HD3DP concept is the result of a combination of print-head technology, materials advancement, firmware and mechanical design. Z Corp.'s 3D printers control the print head movement while positioned extremely close to the powder, reducing inaccuracies related to fanning of the binder spray. The materials used for the automotive part made on Z510/Cx were plaster-based ZP102 powder and water-based Zb56 binder. The technical characteristics of materials can be found in the literature. The built 3D printing model of automotive part is shown in Fig. 3.

Reverse engineering: Computerized digital manufacturing process starts from RE operation. The RE technique has widely applied in all kinds of areas, such as manufacturing, medical applications, automotive and aerospace industry, fabrication and design of arts, etc. It has obvious attributes in terms of shortening the design-to-market process and effective use in conjunction with other time compression technologies and rapid replication process, such as CAD/CAM/CAE and RP/RT. RE refers to the process of creating a CAD model from a physical part or prototype. Different methodologies of RE are used to produce a CAD model from the digitization of a given object by using a 3D scanner system (Chang *et al*., 2006; Varady *et al*., 1997; Yau, 1997; Motovalli, 1998).

There are two phases in the RE process:

- Digitizing or measuring of a mechanical component
- Three dimensional modeling of the part from the digitized data

Once the surfaces have been derived from the digitized data, they are processed into a solid model. The solid model can be exported to CAD/CAM or into the STL file for RP systems. Once, the file has been transferred to CAD/CAM or RP systems, the replica of the scanned model can be produced. Typically, there are four steps in the reverse engineering process:

- Data digitization
- Coordinates reconstruction
- Data point manipulation
- Surface approximation

Data digitization: The first step of the RE process is to capture information describing the physical components features. 3D scanners are employed to scan the component, producing cloud of points, which as a whole define the surface feature. These scanning devices, which are available as dedicated tools or as additions to existing CNC machine tools-fall into two distinct categories: contact and non-contact (also referred to as tactile and remote sensing, respectively) (McDonald *et al*., 2001). The physical object can be digitized using contact 3D scanning technologies like Coordinate Measuring Machine (CMM) or non-contact 3D scanning technologies like laser scanners, structured light digitizers, etc. The mechanical contact measurement equipment, such as a CMM equipped with a touch probe, is an important digitizing tool for data acquisition because its measurement accuracy can achieve up to 10 μm or better (Liu *et al*., 2003). Non-contact 3D scanners can be further divided into two main categories, active scanners and passive scanners. There are a variety of technologies that fall under each of these categories.

Point clouds themselves are generally not directly usable in most 3D applications and therefore are usually converted to triangle mesh models, NURBS surface models, or CAD models through a process commonly referred to as reverse engineering so that they can be used for various purposes. Techniques for converting a point cloud to a polygon mesh include Delaunay triangulation and more recent techniques such as Marching triangles and the Ball Pivoting algorithm. Applications like Rapidform or Geomagic are used to process the point clouds themselves into formats usable in other applications such as 3D CAD, CAM, CAE or visualization. One application in which point clouds are directly usable is industrial metrology or inspection. The point cloud of a manufactured part can be aligned to a

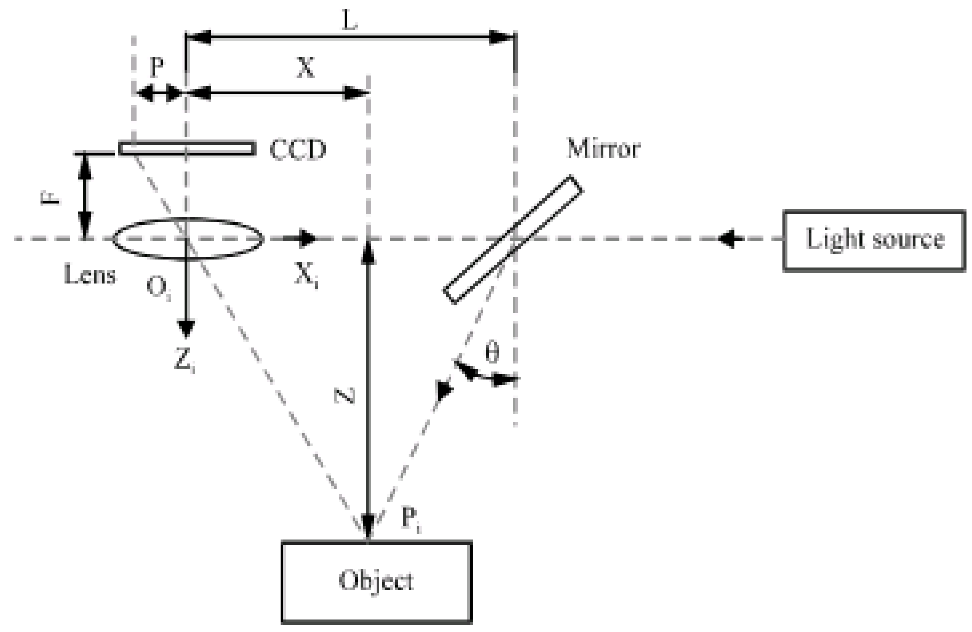

Fig. 4: Triangulation methods for single camera arrangement

CAD model (or even another point cloud) and compared to check for differences. These differences can be displayed as color maps that give a visual indicator of the deviation between the manufactured part and the CAD model. Geometric dimensions and tolerances can also be extracted directly from the point cloud.

The triangulation 3D laser scanner is an active scanner that uses laser light to probe the environment. Most laser scanners use straightforward geometric triangulation to determine the surface coordinates of an object. Triangulation is a method that employs locations and angles between light sources and photosensitive devices (CCD-charge-coupled device camera) to calculate coordinates (Raja and Fernandes, 2007).

Figure 4 and 5 show two variants of triangulation schemes using CCD cameras: single and double CCD camera.

In a single camera system, a device transmits a light spot (or line) on the object at a defined angle. A CCD camera detects the position of the reflected point (or line) on the surface. In a double camera system, two CCD cameras are used. The light projector is not involved in any measuring functions and may consist of a moving light spot or line, moving stripe patterns, or a static arbitrary pattern.

The principle of the triangulation method is shown in Fig. 4. A high energy light source is focused and projected at a pre-specified angle (θ) onto the surface of an object. A photosensitive device senses the reflection from the illuminated point on the surface. Because the fixed baseline length (L) between the light source and the camera is known from calibration, using geometric triangulation from the known angle (θ), the focal length of the camera (F), the image coordinate of the illuminated point (P) and fixed baseline length (L), the position of the

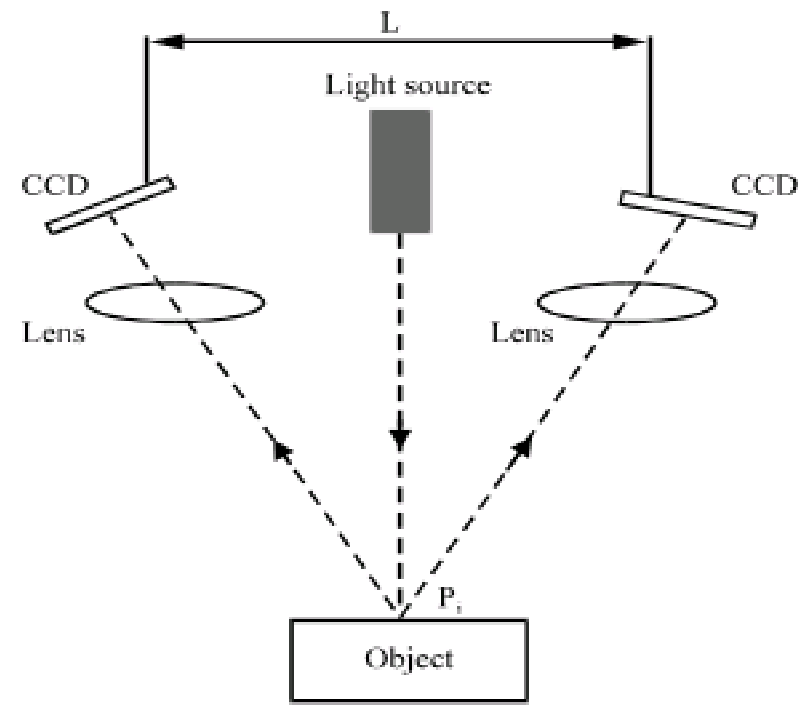

Fig. 5: Triangulation methods for double camera arrangement

illuminated point (P_i) with respect to the camera coordinate system can be calculated as follows (Park and DeSouza, 2005):

$$Z = \frac{FL}{P + F\tan\theta} \quad (1)$$

$$X = L - Z\tan\theta \quad (2)$$

The measurement errors in P and θ can be determined from the Eq. 3:

$$\Delta Z = \frac{Z^2}{FL}\Delta P + \frac{Z^2 \mathrm{Sec}^2\theta}{L}\Delta\theta \quad (3)$$

The error in the Z measurement is directly proportional to Z^2 but inversely proportional to the focal length and the baseline length. Therefore, increasing the baseline length can produce higher accuracy in the measurement. For practical reasons, the baseline length cannot be increased at will and it is limited by the hardware structure of the scanners. Therefore, triangulation scanners are commonly used for scanning small objects over short distances.

Handheld laser scanners create a 3D image through the triangulation mechanism described above. In this research ZCorp.'s Handheld Scanner 700 used for 3D scanning and producing point cloud of RP model (Fig. 6). It is triangulation laser 3D scanner with double camera arrangement.

Coordinates reconstruction: After the data parts have been digitized, these parts are processed into a model rebuild process. The first step is the reconstruction of the coordinates. Generally, the component needs to scan several regions in the scanning process. For each scan, each data file has its own coordinate system. During the stitching process, two files of data have to compute and transfer, to synthesize into a single coordinate system. The process of coordinate reconstruction is also a time consuming task, when doing data transformations by computer.

Data point manipulation: The pre-processing of measured data should include data point manipulation and characteristic line definition. Data point manipulation contains data point sorting, rearrangement, segmentation, reduction, smoothing and extraction. This process can eliminate the noise of data measuring.

Fig. 6: Digitization of RP model by handheld laser scanner

Surface approximation: Once, the noise of digitized data has been removed, the next step is to derive the surface approximation. The surface approximation uses the digitized data as inputs, to derive the surface model using the reverse engineering software.

RESULTS AND DISCUSSION

In this study, an automotive test model was made using the layered manufacturing process RP fabricator, a 3D Printing RP system, instead of NC-CAM system. RP process only took a fraction of the time to make the design prototypes. The conventional NC-CAM process requires skilled operators to plan tool path and NC programming. The NC-CAM process also needs fixture and jig tooling to assist fabrication. This subtractive process, NC-CAM, is inadequate to make sophisticated geometry. In contrast, RP fabricators generate prototypes in a fraction of the time with little human assistance. The additive manufacturing process, RP is a totally automated manufacturing process. It shows more effects that more complicated prototypes are made.

To study the deviation encountered by the produced RP model compared to the actual CAD data, Computer-Aided Verification (CAV) using a handheld laser 3D digitizer is employed. Handheld laser 3D digitizer is used to scan produced prototype. The generated scan data is then matched against original CAD data and a colored plot showing the difference in dimensions of both data sets is obtained. Figure 7 and 8 show the color plots obtained from dimensional analysis carried out on RP model.

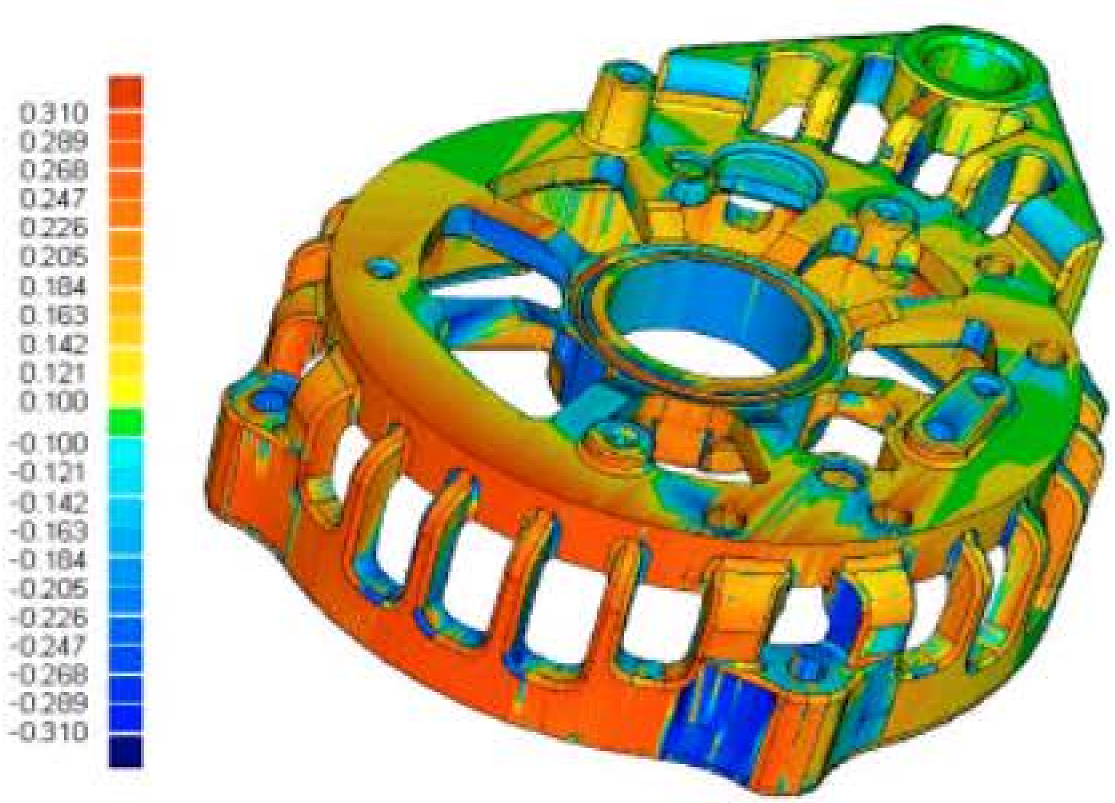

Fig. 7: Deviation color plot of RP model (front view)

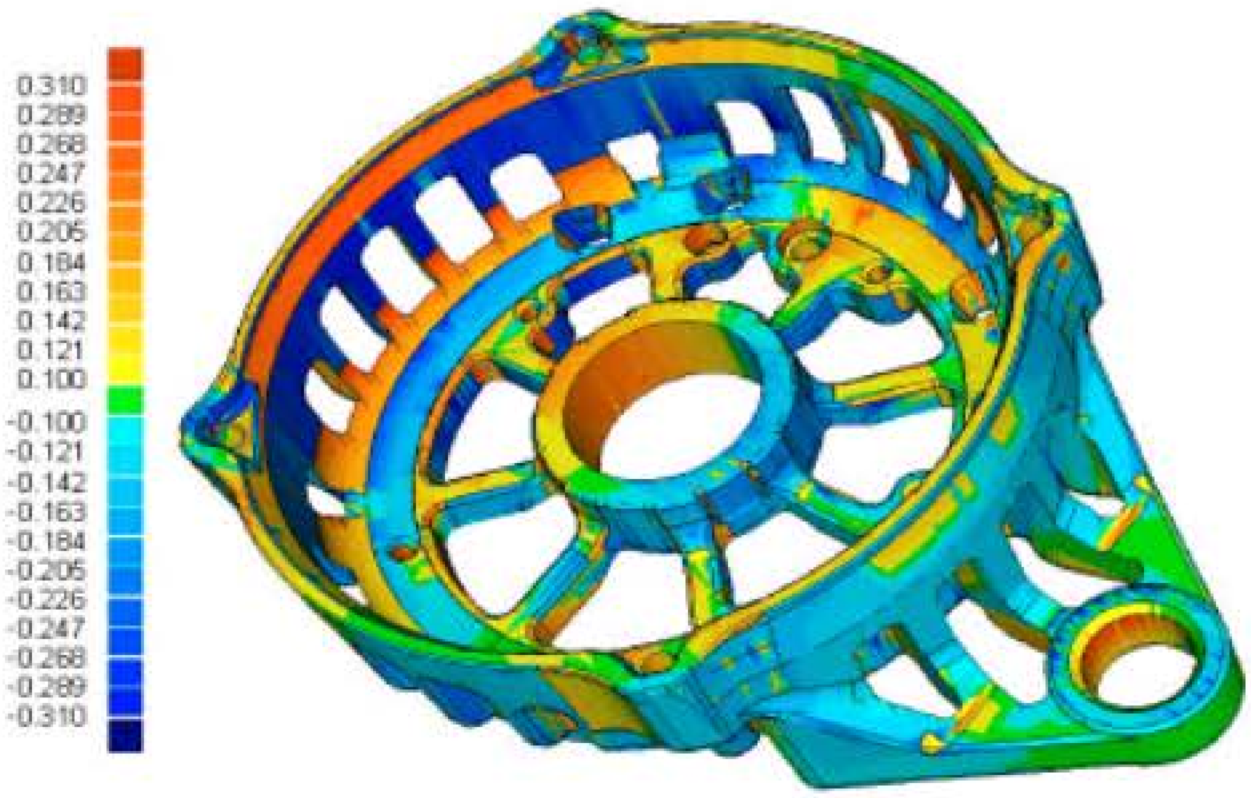

Fig. 8: Deviation color plot of RP model (back view)

Table 1: The results of inspection

Data points No.	Max deviation +/-	Average deviation +/-	SD
115066	+0.298/-0.306 mm	+0.146/-0.125 mm	0.068 mm

Table 2: The percentage of deviations

Confine of deviation (mm)	Points No.	Percentage
-0.310/-0.289	477	0.415
-0.289/-0.268	1429	1.242
-0.268/-0.247	1563	1.358
-0.247/-0.226	1791	1.556
-0.226/-0.205	2279	1.981
-0.205/-0.184	3368	2.927
-0.184/-0.163	4868	4.231
-0.163/-0.142	7690	6.683
-0.142/-0.121	8973	7.798
-0.121/-0.100	9460	8.221
-0.100/+0.100	13854	12.040
+0.121/+0.100	10498	9.123
+0.142/+0.121	9536	8.287
+0.163/+0.142	8843	7.685
+0.184/+0.163	6366	5.532
+0.205/+0.184	5101	4.433
+0.226/+0.205	4705	4.089
+0.247/+0.226	4661	4.051
+0.268/+0.247	3239	2.815
+0.289/+0.268	3135	2.725
+0.310/+0.289	1246	1.083

Dimensional analysis handled by Geomagic Qualify software (powerful software for reveres engineering applications). The amounts of shrinkage and deviations encountered by the prototype can be studied and evaluated from available color plots. As seen, maximum deviation was −0.306 mm. Table 1 shows results of inspection. As seen in Table 1, Standard Deviation (SD) was 0.068 mm.

Also, with proposed integrated technique of 3D scanning with reverse engineering and rapid prototyping technologies statistical analysis of dimensional error can be easily performed. Table 2 shows percentage deviations.

As shown in Table 2, maximum distribution of deviation is 12.040% that is related to the deviations between −0.100 to +0.100 mm. Considering these useful statistical data, it can expect a substantial improvement in quality control process of quick response products.

Therefore, with proposed integration of a 3D scanner, reverse engineering and rapid prototyping technologies, it is possible to improve the efficiency of total quality control for quick response product manufacturing. Experimental results demonstrate that the dimensional error comparisons and statistical analysis can be analyzed and printed out directly and easily. Using conventional tools, it is difficult to validate and analyze the dimensional comparisons of fabricated parts of free form shape or soft material made products and CAD design model. The proposed procedure is effectively able to complete the total quality control task of quick response industries. It is capable of measuring the dimension of products precisely and quickly. The result shows that this proposed method is also effective for soft material or fragile part dimensional comparison.

CONCLUSION

Applications of integrated RE/RP/RT technologies are spreading into industrial areas worldwide. For the sake of global competition in the 21st century and the need to make molds quickly, manufacturers introduce new time-compression mold fabricating methods and invest effective equipment to shorten time-to-market and reduce costs of new product development. That is, how to optimally and efficiently utilize expensive equipment multi-functionally is one of the major concerns of manufacturers. By using 3D scanning and reverse engineering technology in conjunction with rapid prototyping technology, the geometric data of components can be easily and rapidly measured and analyzed. The detailed report can be printed out directly to fulfill the requirement of total quality control for quick response products. The proposed technique is especially suitable for fragile or soft material made products, like thin shell or rubber parts. With its accuracy and ease of operation, this integrated method is able to help manufacturers improve their global competitiveness.

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