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Manufacture of Automotive Component Using Reverse Engineering and Manufacturing Additive Techniques

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ABSTRACT

Reverse engineering is an extraction process of design data from an existing product in order to get its 3D model by data acquisition method. This type of engineering is often applied in software engineering, biomedical field, and parts restoration. The main reasons for implementing reverse engineering are due to obsolete parts, unavailable spare parts and the absence of documentation design.. The objective of the work is to reproduce an automotive part utilizing a 3D printer from data acquisition and CAD model. The reverse engineering technique in this work involves data acquisition, surface and model construction, post-processing and fabrication of the final product. One of the equipment in the non-contact method, the 3D scanner is used to extract design data from the master part. Then, the scanned model is transferred to Solidworks in order to reconstruct the missing features in the model. The findings show that the reverse engineering technique used in this work can reproduce the automative part which is near net-shape of the master part. However, the CAD model require some surface and model reconstruction due to data loss during the conversion of information from scanning data to CAD data. After the final product is fabricated using a 3D printer, it is compared with the master part in terms of the difference of dimensions found between them. Besides, the data loss occurred throughout data acquisition is also discussed in this work. As a conclusion, reverse engineering should be the best alternative to reproduce an object without any design details provided.

Keywords: *Reverse engineering; Automotive part; 3D scanning; 3D CAD; 3D printing*

1. INTRODUCTION

Reverse engineering is a concept that shows the process of extracting engineering design data from existing components. The term “reverse” is used because it is to describe the process in which product development is following a reverse order [1]. Paulic et al. [2] said that it is a type of engineering which takes advantage of an already produced object and its purpose is to create another object similar to the existing object. In simpler words, reverse engineering can be defined by the reverse process of the design activity. The main reason to apply this type of engineering is to go back to the results of the original design process in order to create a copy of the product [3]. Zhou [4] stated that reverse engineering is a method to reconstruct CAD models from physical models. The process in reverse engineering is like a 2D photocopier taking a piece of paper and producing a copy just like the original..

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The primary justification for using reverse engineering is the lack of documentation for an existing mechanical component due to its obsolescence and lack of availability. The issue with reverse engineering is mirrored on the component's surface, which impacts the scanning outcomes because of the reflective quality. The technique has been employed by earlier researchers to quickly replace broken or damaged parts. With the use of 3D scanning technology, the designer can quickly transfer their design to CAD software [2, 5-6]. This technology can decrease the time needed for prototypes creation and also the time needed for real product production. Anggoro et al. [7] apply reverse engineering technique to produce ceramic plates because it will decrease experimental time and cost.

Reverse engineering is applicable to many fields such as software engineering, automotive, consumer products, microchips, chemicals, electronics and mechanical designs [1]. In the automotive industry, this type of engineering application is an important part of the automotive creation process. Martorelli et al. [8] implemented the reverse engineering method in the biomedical field which required them to produce a human mandible and maintaining its mechanical behavior. Zhou [4] also stated that an important area of reverse engineering application is to produce customized human surfaces for mating parts including space suits, helmets, and others.

The most common problem faced by previous researchers in reverse engineering is the light reflection on the component's surface which is due to its reflective ability which affects the scanning results [2, 6]. When the light is reflected, the right point cloud cannot be obtained. The matte and bright surface of components are required if we expect a good quality of the 3D scan. The environmental brightness when scanning is also very crucial and need to be considered because bad results will be obtained in bright environments [9]. For that reason, working conditions in a space with the lowest possible lighting level is a priority. Another problem is part of the data and details of the original product can be irreversibly lost [5]. Then, the CAD designer must recreate all the lost features as faithfully as possible. Zhou [4] indicated that the accuracy of any sensing system depends mainly on the resolution of the camera, the chosen field of view and the appropriate illumination. Error in the digitization process may affect by even a small region of shadow in the image.

2. METHODOLOGY

2.1 Identify automotive part

The first process of this work is to identify the most suitable automotive part to undergo the reverse engineering process. Hence, Honda billet distributor cover (Figure 1) was chosen because it has a variety of non-overly simple or overly complex geometries for image capture. The distributor cover contains the geometry of holes, flat surface and curved surface which make it the best automotive part to be tested with image capturing. Throughout this work, the distributor cover is known as the master part. This master part is also chosen since the limitations of image capturing can be tested by its ability to detect the hollow geometry of the master part which is at the bottom.

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Figure 1: Honda billet distributor cover.

2.2 Image capture/data acquisition

For image capturing or data acquisition, the non-contact method is chosen due to its ability to extract the most accurate design data and the ability to scan or detect texture of a surface and objects with complex geometry. The equipment used for this method is Sense 2 3D Scanner as shown in Figure 2.

Figure 2: Sense 2 3D scanner.

However, the effectiveness of a 3D scanner depends on the workspace, which needs appropriate lighting to produce better results. When the scanning model is not satisfactory or design data is incomplete to rebuild 3D, the image capturing process is repeated until the master part is scanned completely. After several scanning trials, the best-scanned model is obtained under a good lighting environment.

2.3 Surface and model construction

After extracting the design data from the master part, the data is transferred to CAD software to reconstruct its 3D model. Solidworks is used throughout this work to reconstruct the 3D CAD model of the scanned model. Before the surface and model construction begins, the scanned model which is saved in an STL file, need to be transferred to Solidworks as a solid body as shown in Figure 3.

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Figure 3: Scanned model is transferred to Solidworks in solid body.

The scanned model can only be edited if it is transferred in a solid body and not graphics body nor surface body. Then, one of the features in Solidworks which is extruded cut is used to create holes on the outer part of the model (Figure 4).

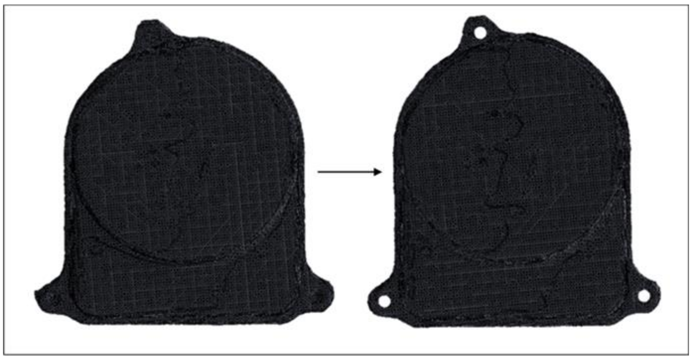

Figure 4: Extruded cut on the outer part of scanned model to recreate the holes.

Furthermore, since the master part cannot be moved while undergoing image capturing, hollow geometry at the bottom of the master part cannot be scanned. To overcome this problem, the extruded cut is also applied to create the hollow geometry to make sure it looks like the master part. The process is displayed in Figure 5.

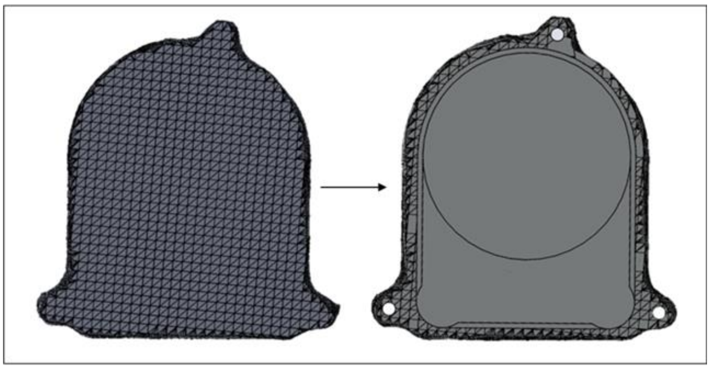

Figure 5: Extruded cut at the bottom part of scanned model to recreate the hollow geometry.

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Other than extruded cut, the extruded boss is also used in the software. This feature gives the ability to fill up holes and defects that can be found in the scanned model. When the scanned model is transferred to Solidworks, there is a hole that can be found on the curved surface.. Hence, as in Figure 6, this feature is needed to fill up the missing design data at the side of the model.

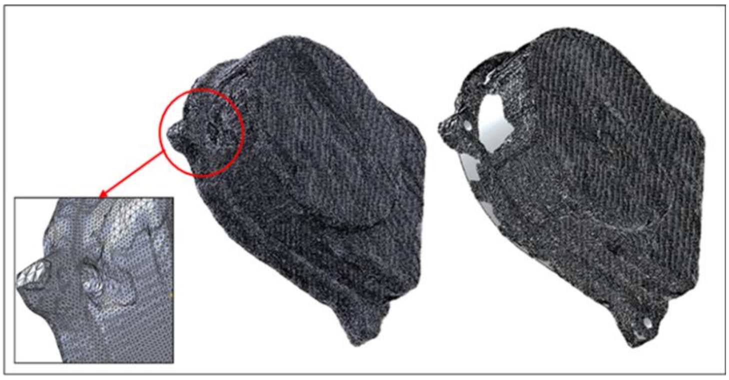

Figure 6: Extruded boss on the curved surface of scanned model to cover up the defects.

2.4 Post-processing

Post-processing or simulation on CAM software is done to make sure the final product can be produced as designed in Solidworks. For this work, the most suitable software would be Cura because it can generate programming language for fabrication process automatically. Cura is an open source 3D printer slicing application, and when the model is transferred to the software, it will generate a specific G-code for 3D printer.

2.5 Fabrication

As for the fabrication process, the final product will be produced using an automated manufacturing machine that can be accessed in campus. The machine is a 3D printer, 3D Espresso F220 (Figure 7) which can also be found in the Industry 1 Laboratory.

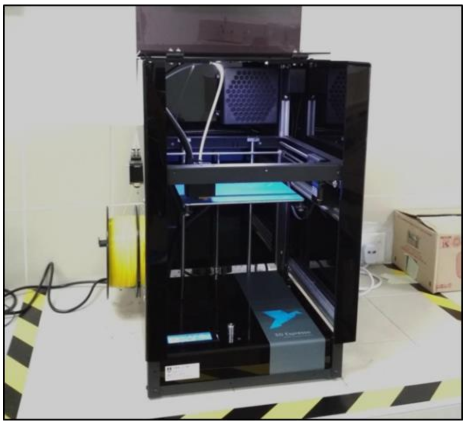

Figure 7: 3D Printing Machine (3D Espresso F220).

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The 3D printing process is chosen so that the final product can be produced with polylactide (PLA) thermoplastic which is the most appropriate material for the final product as it is more precise and results in better quality, and also provides a smoother 3D printing experience. This fabrication process is the opposite of metal-removing in milling or turningin whichit creates a product by laying down layers of material until the whole solid model is completed. The temperature and speed for the 3D-printer are 230□C and 80 mm/s, respectively. After approximately 6 hours of fabrication, the reverse-engineered master part is produced as shown in Figure 8.

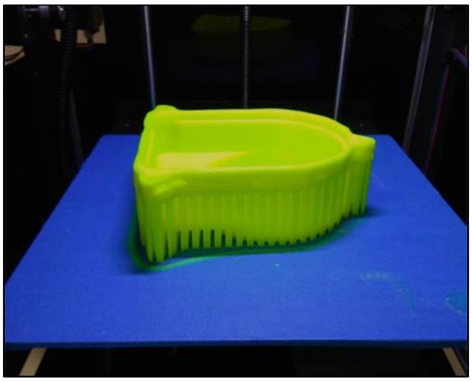

Figure 8: Remanufactured master part.

2.6 Comparison between remanufactured part with master part

For the final process of this work, comparison between remanufactured part and the master part is conducted to observe the difference between them and to study the possible error that happened during the reverse engineering process. The dimensions of both parts are measured to find the percentage error of the final product. The measurement is only done to main parameters of the master part which defined the shape of it. The parameters of master part that are measured is shown in Figure 9. The defects and missing geometric features such as holes, hollow part, flat surface and curved surface in the reverse engineering process are also discussed.

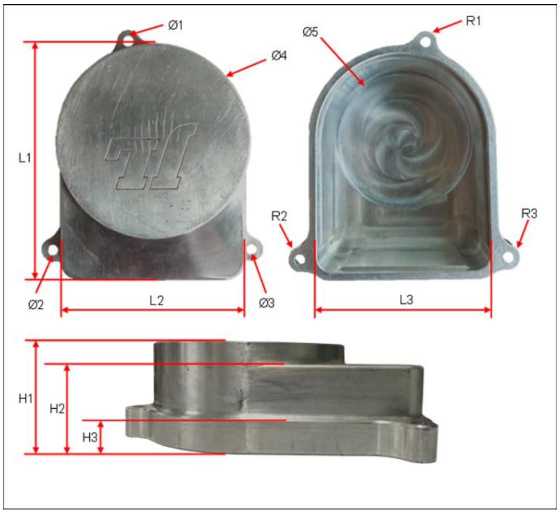

Figure 9: Parameters of master part that are measured to compare the dimensions.

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The dimensions of the final product are measured and compared with the master one to evaluate the remanufacture errors. A vernier caliper is used to measure the dimensions of both parts as it is the most reliable equipment to measure simple parameters such as length, height, and diameter [10]. Other than vernier caliper, radius gauge also used to measure a certain radius on the master part.

3. RESULTS AND DISCUSSION

3.1 Fabrication result

The Honda billet distributor cover is remanufactured using 3D printing machine. Unlike the master part, the final product (Figure 10) is produced with PLA thermoplastic.

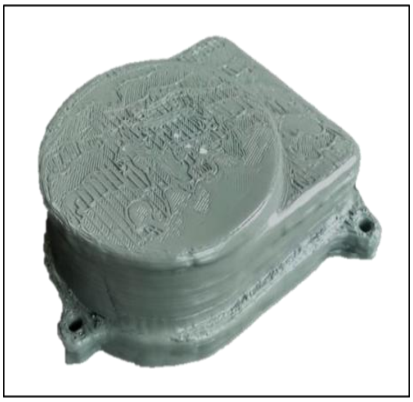

Figure 10: The final product.

3.2 Specification of master part and final product

Based on observation on the master part and final product, the final product is slightly smaller than the master part. The measurement is made in millimeter (mm) with two decimal places to provide greater accuracy. The percentage error is also calculated to identify the different characteristic between the final product and master part. The result is tabulated in Table 1.

Table 1: Measurements of master part and final product.

Dimensions	Master part (mm)	Final product (mm)	Error (%)
Ø1	4.80	4.00	16.67
Ø2	4.80	4.02	16.25
Ø3	4.80	4.00	16.67
Ø4	87.50	87.25	0.29
Ø5	81.00	77.03	4.90
L1	110.00	109.76	0.22
L2	88.00	85.13	3.26
L3	84.70	81.36	3.94
H1	43.00	41.39	3.74
H2	34.50	33.09	4.09
H3	14.00	13.32	4.86
R1	6.50	6.05	6.92
R2	6.50	5.90	9.23
R3	6.50	6.00	7.69

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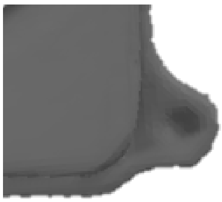
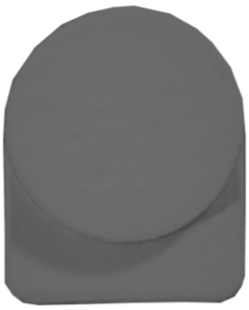
3.3 Data loss during file transferring

Every detail and feature of the master part is considered as important data and they need to be identified because the remanufactured product needs to look exactly like the master part.

Data loss is a common issue during file transfer in the reverse engineering process. Based on observation, missing geometric features are found in the scanned model when it is compared with the master part. The summary of data loss during file transferring is shown in Table 2.

Table 2: Summary of data loss during file transferring.

Features	Master Part	Scanning	Solidworks
1		 -Missing hole	 -Extruded cut to create a hole
2		 -Missing hole	 -Extruded cut to create a hole
3		 -Missing hole	 -Extruded cut to create a hole
4		 -The surface is scanned properly	 -Uneven surface

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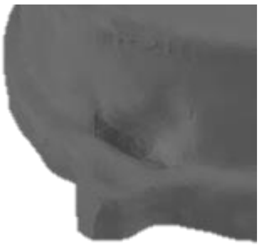
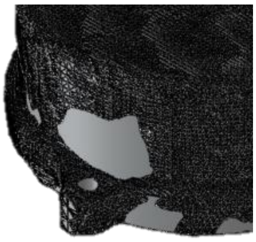
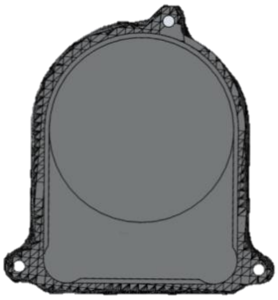
5		 -Defects on a curved surface	 -Extruded boss on curve surface
6		 -Unable to scan hollow part	 -Extruded cut to create hollow part
7		 -Curve edge is not smooth	 -Missing a few points on the edge
8		 -Curve edge is not smooth	 -Missing a few points on the edge
9		 -Curve edge produced is satisfactory	

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10		 -Curve edge produced is satisfactory	
11		 -Curve edge produced is satisfactory	
12		 -Curve edge produced is satisfactory	

3.4 Reasons for remanufacture errors

In the reverse engineering process, it is important to remanufacture the final product as close to the original design of the master part. As stated by Buonamici et al. [11], the final product is required to be correct in dimensions, combinatorial structure and in the existing relations between them. The percentage of inaccuracy is taken into account when producing the final product with a high degree of accuracy.

Based on Table 1, the percentage error for most of the parameters is lower than 10% except for Ø1, Ø2, and Ø3. This percentage error is considered acceptable as the dimensions difference is not too large. This result is expected because most of the features of the master part are successfully scanned and the cloud data is enough to recreate the 3D CAD model. Simple features such as flat surface and curved surface are remanufactured almost like the master part but the only problem is on the complex feature of the master part.

In reference to the image capturing of the master part in this work, Ø1, Ø2, and Ø3, the diameters of holes are not detected by the 3D scanner. This problem is stated by Gapinski et al. [12], where deep holes are difficult to be detected since a number of points scanned are not enough to recreate the hole features of the master part. Thereforeit only relied on surface and model construction in Solidworks to create the holes as in the master part. Recreating the holes in Solidworks is a difficult task because the information obtained is not enough to create the feature exactly like the master part. This explains why the percentage error of the diameter of the holes is slightly higher than other parameters of the master part.

As for R1 to R3, which are the curve edges of the master part, they are critical points that defined the outer shape of the holes. Missing any of them would be a trouble because it is difficult to reconstruct the outer shape. As displayed in Table 1, the radius of curve edges does not differ much from the master part. Further solid and model construction for the edges is not needed in Solidworks as long as their points are scanned for each of the edges.

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3.5 Reasons for data loss

Although the master part is successfully scanned, there are still some data losses on the features of the master part. Based on Table 2, data collected from the image capturing is still not enough to recreate certain features of the master part.

Most of the data loss occurred in scanning, which data acquisition process took place. For instance, the holes on the master part are missing when it is scanned. This is due to insufficient data to recreate deep holes from the master part. Hence, editing the scanned model by using extruded cut in Solidworks is important to recreate the holes as in the master part.

The flat surface of the master part is also somehow affected during the image capturing process. The flaw on the surface is noticed when the scanned model is transferred to Solidworks. As mentioned by Lin et al. [13], noise in cloud data will still occur regardless of using any method in the data acquisition. Somehow, the noise obtained will generate rough edges and surfaces on the scanned model. In this work, the flat surface of the scanned model is uneven due to a lighting problem which occurred during image capturing. This problem also occurred for Features 7 to 12 (Table 2), where the scanned curved edges are not as smooth as the master part. These edges are the critical point on the master part as they defined the outer shape and they are difficult to reconstruct in Solidworks if the data points are missing.

The curved surface is also affected when scanning the master part where defects or holes are found on the curved surface when the scanning is done. This presence of defects is because the scanner is unable to scan the area of notches or steep surfaces as explained by Kumar et al. [14]. In order to fix the problem, the extruded boss is implemented on the curved surface to eliminate the defects by filling up the holes.

For the hollow part of the master part, the 3D scanner is not able to fully capture the image of the master part. The data captured from the scanner did not yield any information that can be used to duplicate the hollow characteristic of the master part. Giri et al. [10] emphasized on the 3D scanner's drawback, in which it is unable to capture the internal details of the master part. The hollow feature is created using extruded cut since it is an important internal feature of the master part.

4. CONCLUSIONS

To conclude, after implementing some techniques in reverse engineering, the master part is remanufactured and looked almost the same as the master part. As stated in the problem statement, reverse engineering techniques are applied in this study because the 3D CAD model of the master part is unavailable due to the lack of documentation access which includes its design data. The image capturing or data acquisition played a crucial role to extract the data from an existing automotive part. However, scanning results shown in the previous section stated that there are errors in the reverse engineering process such as data loss on the scanned model obtained and it still needs some modifications in Solidworks to produce net-shape products. This error must be eliminated or controlled to produce accurate products by implementing surface and model construction on the scanned model. Through this method, the missing features of the master part are recreated in Solidworks. Finally, the goal of the study has been accomplished by showing that the remanufactured product was created utilizing 3D printing without the original master part documentation or information.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest in publishing this paper. Authors have the option to disclose any potential conflicts of interest.

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