THE DEVELOPMENT OF COMPUTATIONAL MODEL THROUGH REVERSE ENGINEERING: SIDE MIRROR CASE STUDY

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ABSTRACT

Reverse engineering is a process of capturing the geometry by existing physical objects and used the data obtained as a foundation for re-designing or designing something new. Laser scanners are commonly used since they can be a sample of three-dimensional range images fast and very accurately relative to other technologies. The complexity of the process to re-modelling the objects is very obvious since the re-shaping of the object is more to surface consideration and not solid modelling. This paper employs and compares two methods of reverse engineering. First, conventional method is used where the parts of a car side mirror are drawn from direct measurement. Second, the detail drawings of the same parts are generated through three-dimensional scanning software. For the conventional method, direct measurements are obtained using a vernier calliper, ruler and micrometer. For the later approach, three-dimensional scanning software is used, where the side mirror and its components are scanned to obtain the initial feature, which later on is refined to achieve an accurate computational model. Based on the final computational model, both methods are compared and analysed. This paper is aimed to exhibit a computer aided reverse engineering approach in modelling a product through both methods. A comprehensive methodology is presented through a case study approach.

KEYWORDS: Reverse engineering, rapid prototyping

1.0 INTRODUCTION

Nowadays, competitive pressure has reached the point, where rapid product design and optimisation need to be embraced within the product development cycle. A short lead-time in product development is strongly demanded to satisfy needs, resulting from the globalisation of manufacturing activities and the changes in market requirements (Zhang, 2003). In engineering areas such as aerospace, automotives, shipbuilding and medicine, it is difficult to create a Computational Aided Design (CAD) model of an existing product that has a free-form surface or a sculptured surface. In these cases, reverse engineering is an efficient approach to significantly reduce the product development cycle. Reverse engineering refers to the process of creating engineering design data from existing parts. It recreates or clones an existing part by acquiring the surface data of an existing part using scanning or measuring device (Lee et.al., 2000). It is useful in creating the CAD model of an existing part when the engineering design is lost or when the model has gone through many design changes. It enables us to capture the surfaces of design models that are otherwise impossible to determine. It also saves us from performing tedious manual dimensioning and tracing work.

2.0 TYPES OF REVERSE ENGINEERING

Reverse engineering has two main types, which are:

2.1 Non-contact Method

Non-contact methods used light, sound or magnetic fields to capture the data. These tend to capture data at faster rate than the tactile methods. Some methods capture large areas of the object at one setting. Others need to take either a line of points or even one point at a time.

2.2 Tactile Methods

These sensors are usually attached to a computerized measuring machine (CMM) or to a dedicated reverse engineering machine. They use various size probes, which touch the object to be scanned in order to gather it is necessary to offset it by the radius of the probe to produce the true surface shape.

Reverse engineering is very common in such diverse fields such as software engineering, entertainment, automotive, consumer products, microchips, chemicals, electronics, and mechanical designs. For example, when a new machine comes to market, competing manufacturers may buy one machine and disassemble it to learn how it was built and how it works. A chemical company may use reverse engineering to defeat a patent on a competitor's manufacturing process. In civil engineering, bridge and building designs are copied from past successes so there will be less chance of catastrophic failure. In software engineering, good source code is often a variation of other good source code. In some situations, designers give a shape to their ideas by using clay, plaster, wood, or foam rubber, but a CAD model is needed to enable the manufacturing of the part. As products become more organic in shape, designing in CAD may be challenging or impossible. There is no guarantee that the CAD model will be acceptably close to the sculpted model. Reverse engineering provides a solution to this problem because the physical model is the source of information for the CAD model. This is also referred to as the part-to-CAD process.

Another reason for reverse engineering is to compress product development times. In the intensely competitive global market, manufacturers are constantly seeking new ways to shorten lead-times to market a new product. Rapid product development (RPD) refers to recently developed technologies and techniques that assist manufacturers and designers in meeting the demands of reduced product development time. For example, injection-moulding companies must drastically reduce the tool and die development times. By using reverse engineering, a three-dimensional product or model can be quickly captured in digital form, re-modelled, and exported for rapid prototyping/ tooling or rapid manufacturing.

TABLE 1
Reason of employing reverse engineering

- A product is no longer produced by the original manufacturer
- The original manufacturer no longer exists, but a customer needs the product
- Documentation of the original design is inadequate
- The original design documentation has been lost or never existed
- The original CAD model is not sufficient to support modifications or current manufacturing methods
- Some bad features of a product need to be designed out. For example, excessive wear might indicate where a product should be improved
- To analyze the good and bad features of competitors' product
- To explore new avenues to improve product performance and features
- To gain competitive benchmarking methods to understand competitor's products and develop better products
- The original supplier is unable or unwilling to provide additional parts
- The original equipment manufacturers are either unwilling or unable to supply replacement parts, or demand inflated costs for sole-source parts
- To update obsolete materials or antiquated manufacturing processes with more current, less-expensive technologies

Reverse engineering enables the duplication of an existing part by capturing the component's physical dimensions, features, and material properties. Before attempting reverse engineering, a well-planned life-cycle analysis and cost/benefit analysis should be conducted to justify the reverse engineering projects. Reverse engineering is typically cost effective only if the items to be reverse engineered reflect a high investment or will be reproduced in large quantities. Reverse engineering of a part may be attempted even if it is not cost effective, if the part is absolutely required and is mission-critical to a system.

Reverse engineering of mechanical parts involves acquiring three-dimensional position data in the point cloud using laser scanners or computed tomography (CT). Representing geometry of the part in terms of surface points is the first step in creating parametric surface patches. A good polymesh is created from the point cloud using reverse engineering software. The cleaned-up polymesh, NURBS (Non-uniform rational B-spline) curves, or NURBS surfaces are exported to CAD packages for further refinement, analysis, and generation of cutter tool paths for CAM. Finally, the CAM produces the physical part.

3.0 LITERATURE REVIEW

In 1997, Yau et.al used reverse engineering technique to develop the design of engine intake ports (Yau et.al., 1997). CMM contact measurement was selected to digitize the complex intake ports. Part segmentation and semi-automatic scanning were applied to the digitization process. For the purpose of data reduction and surface approximation, a new approach to the fitting of rational B-splines was developed. Furthermore, skinning a cross-sectional design technique was utilized to construct the surface to reduce the computation cost. Surface merging was also implemented to maintain the surface boundary continuity. Finally, the enclosed surface volume is produced and can be transferred to commercial CAD/CAM system through IGES translation.

Chen et.al presents a case study on reverse engineering of turbine blades used in nuclear power generators (Chen et.al., 2000). They was developed reverse engineering approach- the modified adaptive model-based digitizing process to the three-dimensional (3D) geometric design of turbine blades. Using this approach, accurate product CAD models can be efficiently generated and the product design cycle of turbine blades can be successfully linked.

Li et.al used reverse engineering system for rapid modelling and manufacturing of products with complex surfaces (Li et.al., 2002). The system consists of three main components: a three-dimensional optical digitizing system, surface reconstruction software and a rapid prototyping machine in developing products with complex surfaces. The unique features of the three-dimensional optical digitizing system include the use of white-light source, and cost-effective and quick image acquisition. The surface reconstruction process consists of three major steps: (1) range view registration by an iterative closed- form solution, (2) range surface integration by reconstructing an implicit function to update the volumetric grid, and (3) iso-surface extraction by the Marching Cubes algorithm. The modelling software exports models in STL format, which are used as input to an FDM 2000 machine to manufacture products.

Hsiao et.al used reverse engineering based approach for product form design. In this method, the designer makes three-dimensional product models based on the ideas with polyurethane or polystyrene foam first (Hsiao et.al., 2003). Then measured the product using a non-contact three-dimensional scan device, and the point clouds for 30 cross-sections of these products are obtained based on the measured information. New shapes are further generated with two different product models using four shape blending/morphing techniques.

Giovanna Sansoni described a very special and suggestive example of optical three-dimensional acquisition, reverse engineering and rapid prototyping of a historic automobile which is Ferrari 250 Mille Miglia, performed primarily using an optical three-dimensional whole-field digitizer based on the projection of incoherent light (OPL- three-dimensional, developed in their laboratory) (Sansoni et.al., 2004). The entire process consists in the acquisition, the point cloud alignment, the triangle model definition, the NURBS creation, the production of the STL file, and finally the generation of a scaled replica of the car. The process, apart from the importance of the application to a unique, prestigious historic racing car, demonstrates the ease of application of the optical system to the gauging and the reverse engineering of large surfaces, as automobile body press parts and full-size clays, with high accuracy and reduced processing time, for design and restyling applications.

Lately, designers gradually make product-models with computer and related equipment automatically instead of manually, due to the rapid progress in computer hardware as well as software. After the CAD/CAM system was introduce into the product development process, the time schedule for product development and manufacture was reduced a lot. In today's highly competitive marketplace like Japan and Europe, along with technology improvement, a good product should not only satisfy consumers' physical requirements, such as the shape of the products, but also should satisfy their psychological needs (ergonomic study). Thus, reverse engineering is a good method for new product-form development.

4.0 METHODOLOGY

The first step in creating a CAD model for an existing part is part digitization. Digitization is a process of acquiring point coordinates from part surfaces. In this paper, direct measurement approach is used to obtain an existing dimension of side mirror. First step, photographic method is used to capture the image. The measurement was done using basic measuring equipment such as ruler, vernier calliper, dial calliper and digital calliper are used to obtain the geometric dimensions for each part.

Another method of measuring the object is using an optical system digitizer. A light or laser beam from its source projected onto a surface, and a camera or detector intercepts the reflected beam and converts it to coordinates. An optical system often referred to as a three-dimensional digitizer is used for automating the reverse engineering of mechanical parts and organic shapes. In this paper, we use non-contact three-dimensional Digitizer VIVID 910 that is a compact and portable state of the art digitizer that is no bigger than a computer CPU. It comes with three interchangeable lenses, Tele, Middle and Wide lens that meet the challenge of scanning objects of different sizes. It is used to build a digital three-dimensional copy of a physical surface without performing any contacts to the object surface. The data is captured to provide in-depth information on complex surface (X, Y, Z coordinates of many points on the surface).

Polygon Editing Techniques (PET) is used to create complete clean, water tight 360 degree virtual model. The three-dimensional Digitizer and/or automatic turntable can be operated from the host computer, perform automatic data registration, edit captured scan data (fill holes, decimate, smooth), merge scans into a single "watertight" mesh, and export to a variety of three-dimensional data formats.

Rapidform2004 is the latest software of reverse engineering. It provides more convenient approach to get dimensional properties. The result of the digitization process is a cloud of two- or three-dimensional data points stored as an image. Light intensity (visual images), nuclear magnetic images commonly known as magnetic resonance images (MRI), and thermal image are several types of two-dimensional images. Light intensity images (LI), which represent the variation of the light intensity over a scene, are the most common two-dimensional images. A three-dimensional image, which is normally called a range image (RI), is a map of depth information at different points on a scene. Range image data can be acquired using one of the available contact or non-contact techniques.

To model the part surface in CAD, its need to identify surface features from the cloud of points acquired by digitization. These features include boundaries and surface segments. The output of the surface segmentation process consists of labelled points belonging to a particular region. Various types of surfaces are used to model the segmented data in CAD. Polynomial functions are used to model standard engineering surfaces such as cylindrical, conical, and others. Free form surfaces are modelled using parametric surfaces such as B-Splines and Bezier surfaces.

5.0 CASE STUDY

5.1 Conventional Method

Direct measurement is used to obtain the dimension of the object in this study. Firstly, a photo of the object was snapped to capture the image. The direct measurement using basic measuring equipment such as ruler, vernier calliper, dial calliper and digital calliper are used to obtain the geometric dimension of each part. Figure 1 show the steps involved in conducting a solid modelling using reverse engineering method.

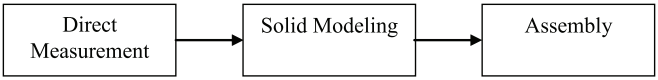

FIGURE 1
Main process flow of conventional method

The useful data is then input into a CAD/CAM system, thereby allowing creation of a three-dimensional wire frame/solid modelling image to be generated and displayed on a monitor. CATIA is used as the CAD/CAM software. A primitive model is then been created, it can be edited, modified to the product requirement. Once the complete car side mirror has been measured, application software is used to create the solid model of all the parts individually. Then, all the parts are assembled digitally to become a complete car side mirror component. It is the last step in convectional method is called assembly.

The development of model are based on feature-based, parametric solid modelling with fully associative three-dimensional solid model with or without constraints while utilizing automatic or user defined relations to capture design intent. The CAD data are featured based structure under Feature Manager design tree by CATIA software which is not only shows the sequence of the features created, it also gives easy access to all the underlying associated information for future modification.

6.0 REVERSE ENGINEERING METHOD

Despite using direct method to reverse engineering, there is software that provides more convenient way to reverse engineering. By using RapidForm2004 software process may be done using scanned three-dimensional images. These dimensional images are a displayed representation of a scene or an object. It is a computer generated representation of reality where it appears to have axes of references which are height, width and depth (similar as x, y, z in Cartesian Space). Figure 3 shows the process flow of the reverse engineering method using Non-contact three-dimensional Digitizer, Polygon Editing Tool (PET) and RapidForm2004 software.

In the figure, it shows the first process of the reverse engineering method using three-dimensional digitizer scanner. Before transform the CAD data to RapidForm2004 software, the product is scanned using the non-contact three-dimensional digitizing scanner. This process is appealing as it is difficult to create computer models of a complex shapes (e.g. organic shapes: human contour)

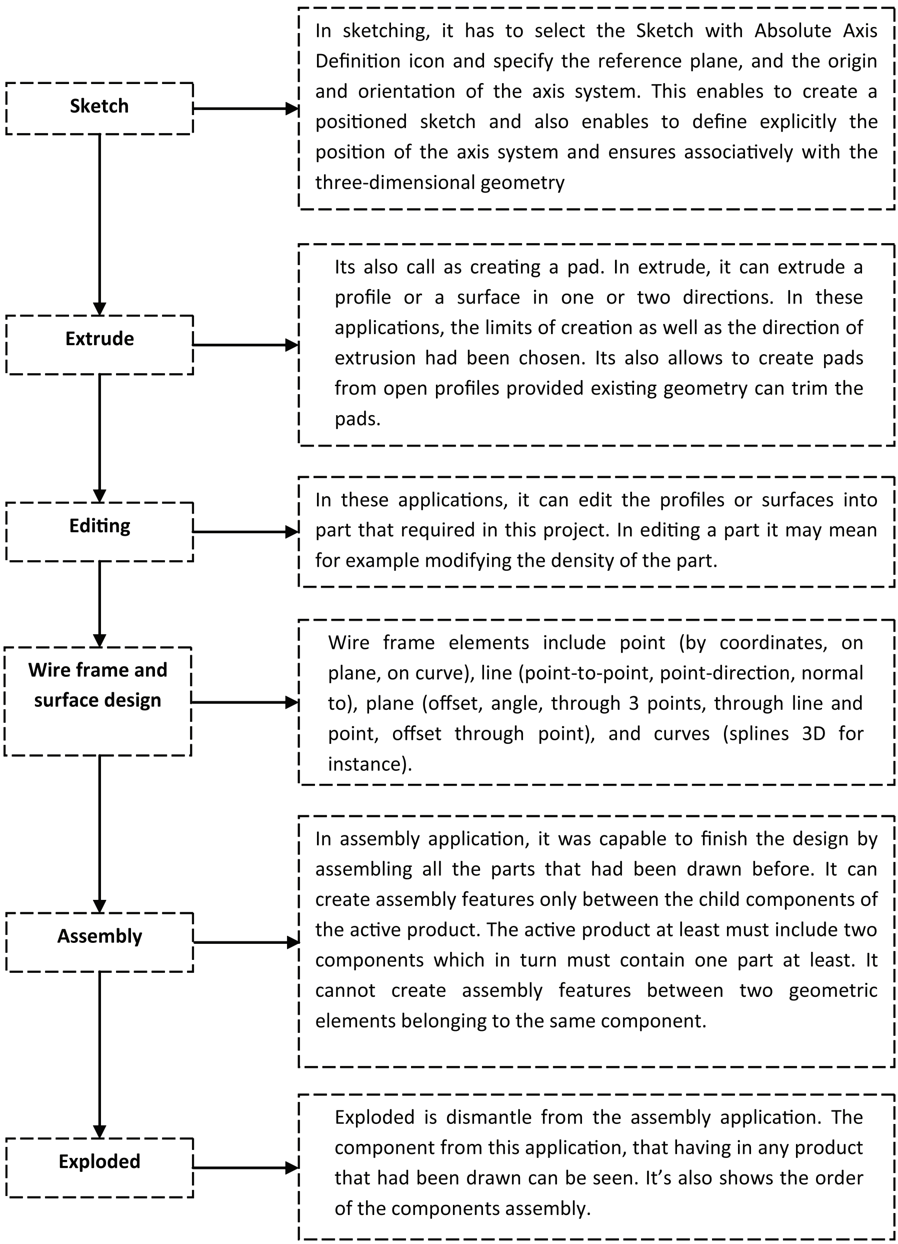

FIGURE 2
Design flow for CAD model creation

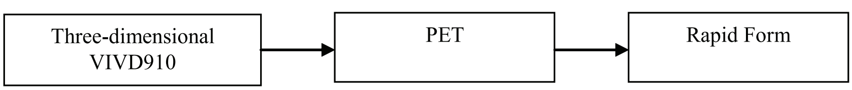

FIGURE 3
Process flow of the reverse engineering method

FIGURE 4
Non-contact 3D Digitizer VIVID 910

The laser light stripe, VIVID 910 can scan over 300,000 points in just 2.5 seconds. VIVID 910 also capture colour images that are equivalent to a 3 CCD digital camera with full 24-bit colour depth. With auto focus functions, the VIVID 910 does away with the need for lengthy set up and calibration time before and during the scanning process. It just frames the object in the LCD viewfinder and presses a button. By having an optional Compact Flash Memory Card the VIVID 910 becomes the world's only truly portable 3D digitizer.

VIVID 910 uses a light stripe method to emit a horizontal stripe light through a cylindrical lens to the object. The reflected light from the object is received by the CCD, and then converted by triangulation into distance (range) information. This process is repeated by scanning the stripe light vertically on the object surface using a Galvano mirror, to obtain a three-dimensional image data of the object. In addition, a colour image of the object is also obtained by scanning the CCD through a RGB filter while the stripe light is not emitted. (A band pass filter is used when stripe light is emitted). Table 2 shows the main features of the non-contact VIVID 910.

The second step in reverse engineering is by using Polygon Editing Techniques (PET) software as shown in Figure 3. After the side mirror was scanned by non-contact three-dimensional digitizer VIVID 910, it will be converted to PET. The side mirror was scanned in different angle before it was merged to get the complete picture of the product. The functions and tools in this software are to create a completely clean and watertight 360 degree virtual model. The three-dimensional Digitizer and/or automatic turntable can be operated from the host computer, perform automatic data registration, edit captured scan data (fill holes, decimate, smooth), merge scans into a single watertight mesh, and export to a variety of three-dimensional data formats. PET has automatic and manual data registration, data merging, holes filling, smoothing, point decimation, polygon checking (intersections, degeneration), and texture blending and merging. Figure 5 and table 3 show PET of car side mirror and main functions of PET respectively.

TABLE 2
The main features of the VIVID 910

Easy to use	No lengthy are set-up, warm-up, and calibration process. With Konica Minolta's precision auto focus, there is no need to move the VIVID back and forth or to manually adjust or guess at the optimal focus. And, it's also no manual adjustment for different ambient light conditions. By using Konica Minolta's optional rotating table, you can index the scanned part and capture all sides in one automated process.
High speed	It can scan 307,000 points in only 2.5 second and 77,000 points in 0.3 seconds.
Portable	The 910 weights approximately 25 lbs and does not require a host computer. Multiple scans can be saved to the compact flash memory or viewed immediately on the rear-panel's colour LCD viewfinder.
Flexible	Digitize variable volumes (between 100x80x40mm and 1200x900x400mm) while maintaining precise repeatability. Three lenses (telephoto, medium, wide angle) are standard equipment and are as easy to change as the lens on your SLR camera.

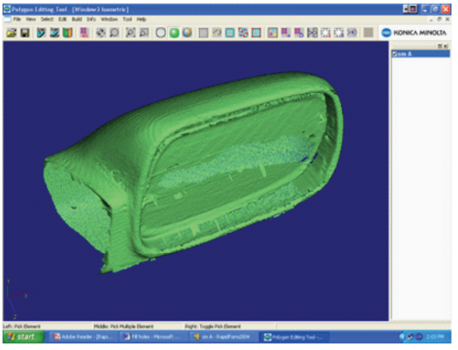

FIGURE 5
PET of car side mirror

TABLE 3
Main functions of PET

	Functions
Point Group Editing	Selection via colour, Bezier and rectangle tools, interactive and parametric rotation, translation of point groups, holes filling on the curve, smoothing, cloning and deletion of point groups. In colour editing, it has colour blending and merging of multiple colour scans.
Camera Remote Operation	Image capture, auto/manual depth-of-field, automatic/manual laser power setting, camera data acquisition control, turntable control.
Scan Data Display Modes	Wire frame, smooth shaded, flat shaded, colour image, texture mapping
Data Format	Import formats : *.stl, and *.cam, *.vvd, *.scn, *.cdm (Minolta proprietary) Export formats, geometry : *.dxf, *.obj, STL Binary, STL Ascii, *.hrc, VRML Export formats, colour image : *.tif, *jpeg, *.ppm, *.bmp

RapidForm2004 is the most powerful full featured software for processing three-dimensional scanned data. It is the bridge between three-dimensional scanners and all other downstream applications, including computer aided design (CAD), computer aided manufacturing (CAM), computer aided engineering (CAE), and others. It converts data from any three-dimensional scanning device which are laser, white-light, touch probe or any others into high quality polygon meshes, accurate freeform NURBS surfaces, or geometrically perfect solid models. RapidForm2004 offers advanced quality inspection technology, allowing scanned data to be compared with CAD design data and a variety of geometric tolerances and dimensions to be measured. To get proper design, we need to go through all the workbenches below.

RapidForm2004 is a comprehensive suite of tools designed to convert real-world data from three-dimensional scanning devices into high quality, accurate and useful data for a variety of applications, which are from reverse engineering parts for CAD/CAM to detailed quality inspection reports to cosmetic surgery planning. Figure 6 shows two sequences of steps that might have to go through during the reverse engineering process. The first sequence of steps is for point clouds of raw input data and the second sequence of steps is for raw point data that is organized sequentially along key paths on the object.

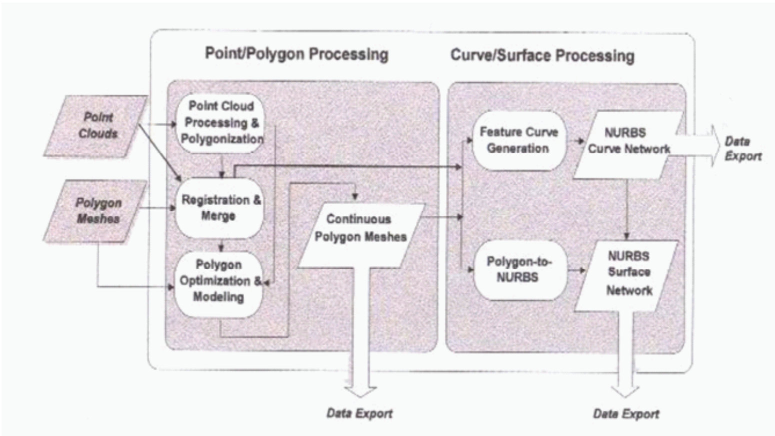

FIGURE 6
Flow process of RapidForm

7.0 RESULTS AND DISCUSSION

In this research, we have performed two approach of reverse engineering methods for a case study of a car side mirror. One is by using direct measurement and the other is by using RapidForm2004 software. The objective of this research is to compare two methods of reverse engineering.

There are many methods for reverse engineering from conventional methods to the latest engineering software. In these research considerations, we used two different approaches for comparison. First approach is conventional method. Conventional method is an old method, which using manual equipment such as ruler, vernier calliper, and micrometer, bore hole and dial calliper to obtain the geometric dimension of the side mirror. It consists of body and motor of side mirror. After the components are measured, the components will be redrawn using CAD software (CATIA) and the results of this method are shown below.

7.1 DIRECT MEASUREMENT

Through the development of each component, the assembly of the parts can be performed using CAD software. By this digital assembly, designer can check the required tolerances that are achievable within the limit of the existing manufacturing process. Tolerance misapplication ultimately affects customer satisfaction, either by compromising product performance and reliability or by the manufacturer having to pass on the higher manufacturing cost to the customer. Figures below show the CAD drawing of the component of the side mirror and exploded and assembly drawing using CATIA.

Component of the Side Mirror

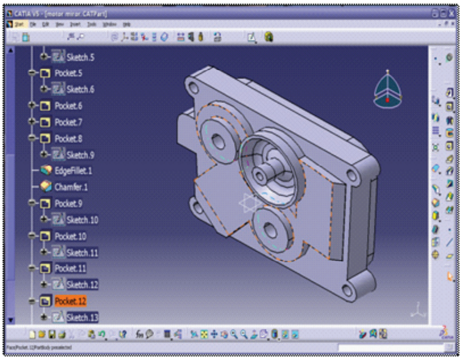

FIGURE 7
Body of side mirror

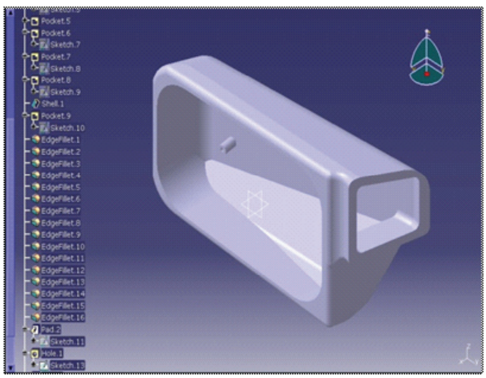

FIGURE 8
Motor of side mirror

Exploded Drawing

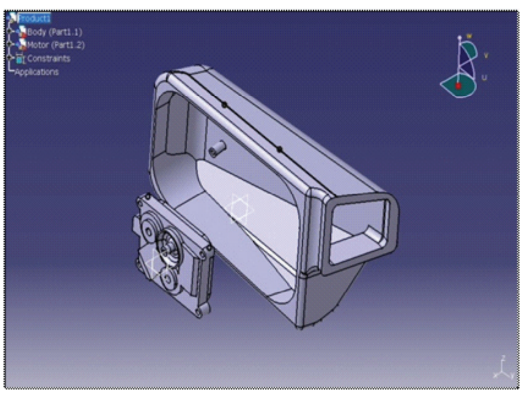

FIGURE 9
Exploded drawing of side mirror

Assembly Drawing

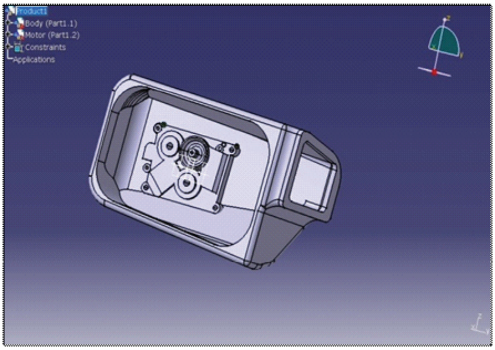

FIGURE 10
Assembly drawing of side mirror

7.2 POLYGON EDITING TECHNIQUES (PET)

In this research, we tried to develop an object using RapidForm software. RapidForm is the latest reverse engineering software, which using a three-dimensional scanner. The object was scanned with three-dimensional coverage using scanning equipment. Konica Minolta Non Contact three-dimensional Digitizer VIVID 910 was used to capture the object. A cloud of points taken from scanned data. It is called point's clouds. Point cloud was captured by VIVID 910 to light-receiving lens based on the reflection of laser beam from model surface. Once the data captured, it will convert the three-dimensional images into point clouds. Those point clouds are saved in PET file. Point clouds could consist of a single point or several million point.

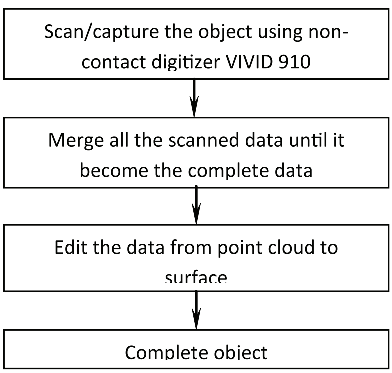

FIGURE 11
Polygon Editing Technique (PET) methods

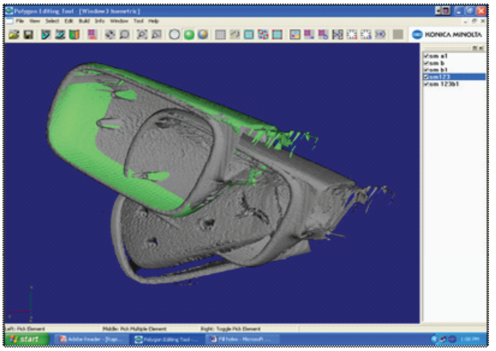

FIGURE 12
Before registration

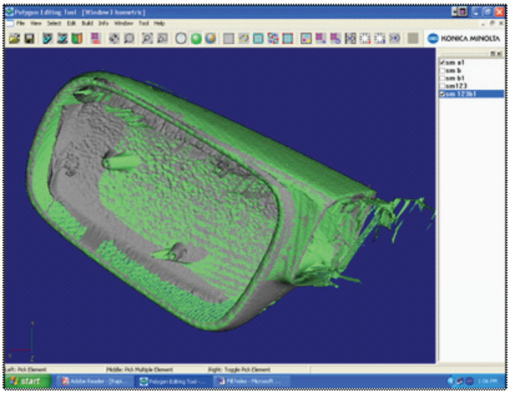

FIGURE 13
After registration

RapidForm2004

Finally, after those components had been edited in PET, then it will be transferred to RapidForm2004 software. In RapidForm2004, the flow of editing those components has to be continued. Special purpose reverse engineering programs may have many tools for performing general three-dimensional shape manipulation, but their main focus is on the process of converting raw point data from the input devices into a more usable polygon or NURB surface representation with the least loss of accuracy. The final three-dimensional computer model passes exactly through all of the raw input data points. This may happen for a polygon model, but the raw data rarely ever matches the exact needs of a NURB surface model and the accuracy is less.

Polygon Workbench

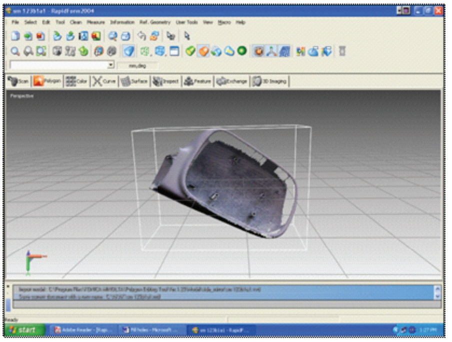

FIGURE 14
Side mirror in RapidForm

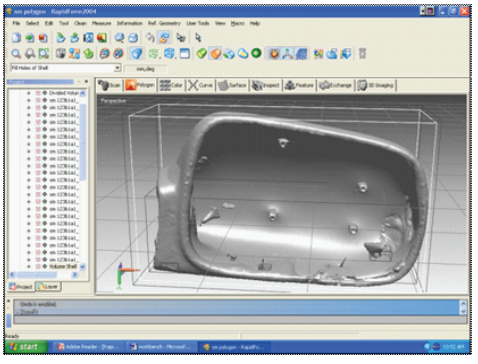

FIGURE 15
After complete the polygon after PET workbench

After all, the point clouds merging to each other, editing the abnormal surface will be done using Polygon Workbench. The Polygon Workbench offers the most comprehensive set of functionalities available to manipulate and prepare polygon mesh models for a variety of applications. It includes virtually every tool needed to create high quality polygon meshes for rapid prototyping, three-dimensional graphics, or downstream applications like NURBS surfacing. RapidForm's powerful hole filling algorithms intelligently fill in missing data, and several methods for surface smoothing can repair common errors in three-dimensional scan data. Figure 14 and Figure 15 show the side mirror in RapidForm after PET and side mirror after completing the polygon workbench respectively.

Colour Workbench

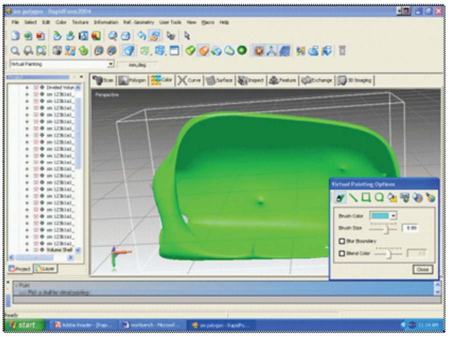

FIGURE 16
Virtual colour

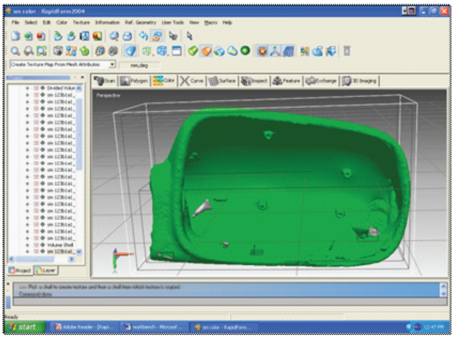

FIGURE 17
The complete colour workbenches from vertex colour to texture

Colour workbench offers the most advanced three-dimensional scan data colour management. Using Photoshop-like colour and texture editing features, users can create perfect three-dimensional colour models of any object. Digital photographs or any two-dimensional bitmap image can be mapped onto a three-dimensional model in RapidForm, making any three-dimensional scanner a colour scanner. Users can collect accurate geometry from three-dimensional scanning devices, then apply accurate photographs to optimized models in RapidForm for the best possible colour/textured models.

RapidForm offers colour management, including virtual painting, blurring, smoothing and more. Text can be added to any model, and brightness and contrast can be adjusted to achieve the perfect photorealistic three-dimensional model. Figure 16 and Figure 17 show the process of the colouring from vertex colour to texture until the end complete colour workbench.

Curve Workbench

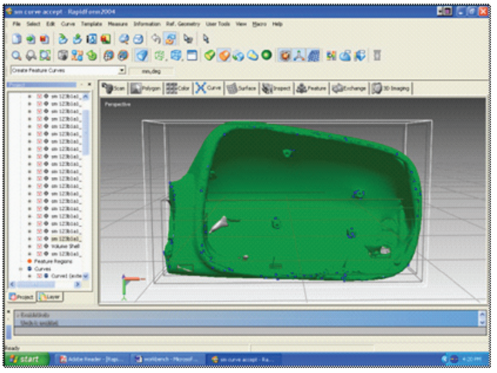

FIGURE 18
Complete featured curve

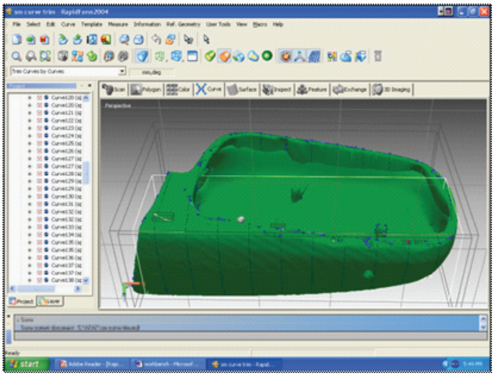

FIGURE 19
Complete trimmed curve

The Curve workbench allows NURBS curves (splines) to be created on a polygon mesh in a variety of ways. The ability to create curves that are tightly mated to the polygon mesh allows the quick design of a custom curve network, perfect for polygon-fit freeform surfacing in RapidForm2004 or for export to CAD for further design and modification. Figure 18 shows the complete featured curve and Figure 19 shows the complete trimmed curve of the side mirror.

8.0 CONCLUSIONS

Reverse engineering of geometric models is rapidly evolving discipline in which interest is currently high. This is due to in no small part to the relatively recent commercial availability of active stereo based laser scanners which are sufficient accuracy for many applications. In summary, from this research, it can be concluded that by using this RapidForm2004 software, any existing object/product can be easily re-engineered. It can shorten the time and reduce the cost of production.

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