ABSTRACT
The process of duplicating an existing part, subassembly, or product without the aid of drawings, documentation, or a computer model is known as reverse engineering. Reverse engineering is also defined as the process of obtaining a geometric CAD model from 3D points acquired by scanning digitizing the existing products. The aim of this paper is to review the reverse engineering process, and its role in the development, refinement and modifications in the existing design of product has been discussed. After a brief introduction, the various stages involved in reverse engineering, and its applications in different fields have been discussed. A brief historical events using reverse engineering technique have also been discussed at length.

KEY WORDS: Reverse engineering, reverse engineering stages, scanners.

1. INTRODUCTION: Due to globalization and trade liberalization, manufacturing companies face tough competition from goods and services produced in lower wage economies. Countries in the West cannot compete against low wages and therefore depend on raising innovations and best practices to create better products. In an attempt to compete in such a volatile environment, companies are looking to lean and agile strategies to compete and survive. Lean or world class manufacturing is principally aimed at reducing waste and controlling things that can be measured and controlled. On the other hand, agility deals with things that cannot be controlled. 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. Approaches such as Rapid Prototyping (RP) and Reverse Engineering (RE) are helping to solve some of these problems.

“Reverse engineering (RE) refers to creating a computer-aided design (CAD) model from an existing physical object, which can be used as a design tool for producing a copy of an object, extracting the design concept of an existing model, or reengineering an existing part.” Yau et al. (1993) define RE, as the “process of retrieving new geometry from a manufactured part by digitizing and modifying an existing CAD model”. Abella et al. (1994) described Reverse Engineering (RE) as, “the basic concept of producing a part based on an original or physical model without the use of an engineering drawing”.

Reverse engineering is now widely used in numerous applications, such as manufacturing, industrial design, and jewelry design and reproduction. For example, when a new car is launched on the market, competing manufacturers may buy one and disassemble it to learn how it was built and how it works. In some situations, such as automotive styling, designers give shape to their ideas by using clay, plaster, wood, or foam rubber, but a CAD model is needed to manufacture the part. As products become more organic in shape, designing in CAD becomes more challenging and there is no guarantee that the CAD representation will replicate the sculpted model exactly.

2. STAGES INVOLVED IN REVERSE ENGINEERING:
Reverse engineering deals with the detailed study of the product including its material, structure, surface qualities, operating conditions etc. The first step involved is the collection of data followed by preprocessing and solid model creation. The stages involved in reverse engineering are:

2.1. Scanning phase: This phase is involved with the scanning strategy—selecting the correct scanning technique, preparing the part to be scanned, and performing the actual scanning to capture information that describes all geometric features of the part such as steps, slots, pockets, and holes. Three-dimensional scanners are employed to scan the part geometry, producing clouds of points, which define the surface geometry. These scanning devices are available as dedicated tools or as add-ons to the existing computer numerically controlled (CNC) machine tools. There are two distinct types of scanners, contact and noncontact.

2.1.1. Contact Scanners
These devices employ contact probes that automatically follow the contours of a physical surface.
In the current marketplace, contact probe scanning devices are based on CMM technologies, with a tolerance range of +0.01 to 0.02 mm. However, depending on the size of the part scanned, contact methods can be slow because each point is generated sequentially at the tip of the probe. Tactile device probes must deflect to register a point; hence, a degree of contact pressure is maintained during the scanning process. This contact pressure limits the use of contact devices because soft, tactile materials such as rubber cannot be easily or accurately scanned.

2.1.2. Noncontact Scanners:
A variety of noncontact scanning technologies available on the market capture data with no physical part contact. Noncontact devices use lasers, optics, and charge-coupled device (CCD) sensors to capture point data, as shown in Figure 3. Although these devices capture large amounts of data in a relatively short space of time, there are a number of issues related to this scanning technology.

- The typical tolerance of noncontact scanning is within ±0.025 to 0.2 mm.
- Some noncontact systems have problems generating data describing surfaces, which are parallel to the axis of the laser (Figure 4).
- Noncontact devices employ light within the data capture process. This creates problems when the light impinges on shiny surfaces, and hence some surfaces must be prepared with a temporary coating of fine powder before scanning.

Advantages:
- No physical contact;
- Fast digitizing of substantial volumes;
- Good accuracy and resolution for common applications.
- Ability to detect colors.
- Ability to scan highly detailed objects, where mechanical touch probes may be too large to accomplish the task.

2.2. Point Processing Phase:
This phase involves importing the point cloud data, reducing the noise in the data collected, and reducing the number of points. These tasks are performed using a range of predefined filters. This phase also allows us to merge multiple scan data sets. Sometimes, it is necessary to take multiple scans of the part to ensure that all required features have been scanned. This involves rotating the part; hence each scan datum becomes very crucial. Multiple scan planning has direct impact on the point processing phase. The output of the point processing phase is a clean, merged, point cloud data set in the most convenient format.

Figure.5. Parts of the brake
Multiple view scanning and registration overcome occlusions. Part of the brake is excluded in each of the views above. When these views are registered together, one view fills the occluded regions of the other view.

2.3. Application Geometric Model Development Phase:
The generation of CAD models from point cloud data sets is the final phase in the process. The output of the point processing phase is a clean, merged, point cloud data set in the most convenient format. Commercial software is available for this phase, which can hold up to 2 million scan points. The output of this phase is a geometric model that can be used for various applications, such as design, manufacturing, and quality control.
data is probably the most complex activity within RE because potent surface fitting algorithms are required to generate surfaces that accurately represent the three-dimensional information described within the point cloud data sets. Most CAD systems are not designed to display and process large amounts of point data; as a result new RE modules or discrete software packages are generally needed for point processing. Generating surface data from point cloud data sets is still a very subjective process, although feature-based algorithms are beginning to emerge that will enable engineers to interact with the point cloud data to produce complete solid models for current CAD environments.

3. LITERATURE REVIEW:
A large volume of literature is available in journals and books explaining the process of Reverse Engineering and its applications in the various fields. In this chapter, a review of relevant literature has been made. The survey of literature was based on the applications of Reverse Engineering in automotive and mechanical parts, and other related parts. There are many studies which are contributed by many researchers and engineers regarding the applications of Reverse Engineering, some of which are as follows:

Lee et.al. (1998) proposed a novel procedure that integrates technique of Reverse Engineering (RE) and Rapid Prototyping (RP) technology.

Z.Q. Cheng et. al. (2001) reported the experiences encountered during the development, modifications, and refinement of a finite element model of a four-door 1997 Honda Accord DX Sedan. A single Finite element crash model was developed for a four-door 1997 Honda Accord DX Sedan. This model was successfully used in the simulations of the full frontal, offset frontal, side, and oblique car-to-car impacts. The simulation results were validated with test data of actual vehicles. The validation indicated that the model was suitable for use as a crash partner for other vehicles. Computational tests of the model show that the model was computationally stable, reliable, and repeatable. Feng et al. (2001) presented the effects of the scan depth and the projected angle on the digitizing accuracy of a laser/CMM scanning system. Speckle noise in the CCD laser images was considered the primary source of random error. A bilinear empirical model had been established and was able to provide predictions of the systematic error with less than 25 µm deviation.

Son et al. (2002) had proposed an automated laser scanning system which could automatically generate a scan plan by investing a complex free-form part whose CAD model was given (Lee and Woo, 1998). The automated part positioning system could save much time, improved the quality of captured data and the registration process was simplified. Thereby, redundant data processing was drastically reduced and errors caused by human operator could be minimized. Bardell et al. (2003) had proposed a method of automating the verification of an acceptable free-form surface, using Coordinate Measuring Machine (CMM). Computer-aided geometric design (CAGD) was used to analyze the surface for optimum continuity and assessed the CMM data accuracy. Park and Chung (2003) had proposed a procedure through which 3-axis NC tool-paths (for roughing and finishing) could be directly generated from measured data (a set of point sequence curves). An algorithm to calculate the finishing tool-path based on well-known 2D geometric algorithms had been developed to avoid difficult time-consuming computational.

Xie et al. (2005) had presented a multi-probe measuring system integrated with a CMM, a structured-light sensor, a trigger probe and a rotary table. Two types of scanning modes which were multiview scanning mode and rotating scanning mode had been used (Chung and Liao, 2001). Lin et al. (2005) had presented the measure method to get the better data points and the appropriate method to deal with points cloud data. Reverse engineering software was then used to create the free-form surfaces from the point cloud data. Mohammad Shadab et. al. (2006) presented the applications of the reverse engineering method on the modeling of Pillion step holder of Hero Honda CBZ Motor Bike. The CAD model of Pillion step holder had been developed by CATIA V5 using the cloud data. The stress analysis of pillion step holder was also done. Results had shown that the maximum stress at critical section was within the permissible limit as compared to the strength of the material and the deflections in the component were much lesser than the permissible value. Again the stress analysis was performed on the modified CAD model. It was found that the maximum stress and maximum deflection was still within the permissible limit. It also helped to understand the behavior of the CAD model under various loading conditions and further helped to modify it. F. Belarifi et. al. (2008) proposed a method to optimize the module of cutting conical spur gear, after being worn or broken, with the aid of Computer-Aided Design (CAD). It also allowed creating a virtual model, by theoretical geometric characteristics, to calculate the volume. The suggested method allowed determining the geometric features of a pair of conical spur gear after worn. A simulation package, R2000, was used and special “AutoCAD” software had been developed to accomplish the drawing of 2D wheel conical spur gear, the verification of the system assembly and the drawing of a 3D volume pattern. M. Manzoor Hussain et. al. (2008) presented the development of
computer technology resulted in the integration of design and manufacturing systems and automated inspection/gauging systems in manufacturing engineering applications. Geometrical information of a product was obtained directly from a physical shape by a digitizing device, from this complete 5-axis tool-path was obtained. Duplicating the part was done with the help of CMM and CAD/CAM software like Mastercam, ProEngineer etc. CMM was used to digitize the mechanical object. Taking coordinates (scan data) of the various points on the surface of the object and converting it into IGES file and using the same in the CAD/CAM software with required interfacing created a surface or solid model of the object. Finally this solid model was used to generate CNC part program to manufacture the part on CNC Machining center [12], A.R. Ismail et. al. (2009) explained the modeling and machining of four stroke piston engine using Reverse engineering method. The process included digitizing process by using layout machine to capture the point clouds and following by the Computer Aided Design (CAD) stage and Computer Aided Manufacturing (CAM) stage using Unigraphics NX2 software to reconstruct the piston engine surface. Then, machining process with Computer Numerical Control (CNC) machine was used to create the piston head engine. Finally, the accuracy of the replicated piston engine was checked by using Coordinate Measurement Machine (CMM) and block gauge [13]. Bhupender Singh et. al. (2011) presented the solid modeling and finite element analysis of crane boom using PRO/E WILDFIRE 2.0 and ALTAIR HYPER MESH with optistruct 8.0 solver Software to get the variation of stress and displacement in the various parts of the crane boom and possible actions were taken to avoid the high stress level and displacement. The solid model was created using pro/E Wildfire 2.0 using given dimensions. Then the solid model was imported to ALTAIR HYPER MESH and analysis of the model was carried out in OPTISTRUCT SOLVER 8.0 under given constraints. The stress values calculated for three load points were found to be under the limits of ultimate tensile strength and yield strength of boom material. So it can be said that under the given conditions of boom material and load carrying capacity, crane boom was safe to lift the load up to 12 Tonne [14].

4. APPLICATIONS:
Reverse engineering (RE) is the process of creating a CAD model from a physical part or prototype (Varady et al., 1997). In the conventional product development cycle, the initial conceptual or aesthetic design of sculptured surfaces is often described by stylists who formalize their ideas by making clay or wooden models. Recently, RE is increasingly employed in medical applications. For example, physical models are molded from a part of the body, such as the stump of an amputated limb, and an appropriate model is then captured and developed from the mold and used to custom-fit an artificial limb. Necessary CAD models can be generated using RE technology based on the corresponding geometric database, which is usually created by capturing the shape information from the original physical model by mechanical contact or optical noncontact measuring techniques.

In the realm of mechanical engineering alone, reverse engineering techniques can be used for:

- Inspection of parts and comparison of the actual geometry with computer aided design (CAD) models.
- Capturing the shape of an existing part, possibly one that is obsolete, so that a replacement part can be manufactured through a rapid prototyping approach, numerically controlled (NC) machining of surfaces interpolated through the captured points.
- Capturing the deformed shape of an object, after some sort of impact test, to compare the actual deformed shape with that predicted by finite element analysis.
- Capturing the geometry of an existing factory or process plant, to allow using a CAD system for piping, heating, ventilation, and air conditioning (HVAC) design etc.
- Wear measurement of tooling.

But if the list of mechanical engineering applications alone seems endless, there are applications in medicine, such as prosthetic design and manufacture, aerospace industry, animation, civil engineering, and many other fields.

5. CONCLUSIONS:
Reverse engineering is the process of investigating the technological principles of a device, object or system through analysis of its structure, function and operation. It often involves taking something (e.g., a mechanical device, electronic component, or software program) apart and analyzing it in detail which is to be used in understanding the structure & functioning of the object or to try to make a new device or program that does the same thing with more efficiency than the existing system. The purpose is to deduce design decisions from end products with little or no additional knowledge about the procedures involved in the original production. As computer-aided design (CAD) has become more popular, reverse engineering has become a viable method to create a 3D virtual model of an existing physical part for use in 3D CAD, CAM, CAE and other software. The reverse-engineering process involves measuring an object and then reconstructing it as a 3D model. The physical object can be measured manually using gauges, scales & meters or with the help of computers using 3D scanning technologies like CMMs, laser scanners, structured light digitizers or computed tomography. It is a process that can reduce the product development cycle besides cost saving. Effective use of reverse engineering application is expected to penetrate market in the future.

REFERENCES:
the International Societies for Precision Engineering and Nanotechnology, vol: 25, pp.185-191.


