Review on study of Reverse Engineering in Mechanical

Pooja Adate[1], Prof. Amar Pandhare[2]

[1]*Student, Mechanical Department, SMT. Kashibai Navale college of engineering, Pune.* ***poojaadate7@gmail.com***
[2]*Head of Department, Mechanical Department, SMT. Kashibai Navale college of engineering, Pune.*
Amarppandhare@gmail.com

ABSTRACT

In medical devices design, reverse engineering principles are more often used in implants designing and specifically in orthopedic implants designing. 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. The complexity of the process to re-modeling the objects is very obvious since the re-shaping of the object is more to surface consideration and not solid modeling. Laser scanners are commonly used since they can be a sample of three dimensional range images fast and very accurately relative to other technologies.

Keywords: ***FEM modelling, orthodontic, reverse engineering, Reverse engineering, rapid prototyping, simulation***

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1. INTRODUCTION

Reverse engineering is the opposite of forward engineering. It takes an existing product, and creates a CAD model, for modification or reproduction to the design aspect of the product. It can also be defined as the process or duplicating an existing component by capturing the components physical dimensions. Reverse engineering is usually undertaken in order to redesign the system for better maintainability or to produce a copy of a system without access to the design from which it was originally produced. With this knowledge, computer vision applications have been tailor to compete in the area of reverse engineering. Computer vision is a computer process concerned with artificial intelligence and image processing of real world images. Three dimensional (3D) computer visions use two-dimensional (2D), images to generate a 3D model of a scene or object.

There has been a mandatory need for 3D reconstruction of scenes and objects by the manufacturing industry, medical industry, military branches and research facilities. Manufacturing industry utilizes reverse engineering for its fast rapid prototyping abilities and accuracy associated with the production of new parts. This fast prototyping is done through the use of CAD model designs for inspection purposes.

2. TYPES OF REVERSE ENGINEERNG

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.

3 STEPS OF REVERSE ENGINEERING

The goal of reverse engineering an object is to successfully generate a 3D CAD model of an object that can be used for future modeling of parts where there exists no CAD model. We want to generate clean, smooth 3Dmodels, which are free of noise and holes. This requires a strong, robust image acquisition system that can acquire data with a high level of accuracy in a sufficient timeframe. Our system uses range and intensity images of objects as input. The output is transformed data that is represented as 3D reconstructions of geometric primitives.

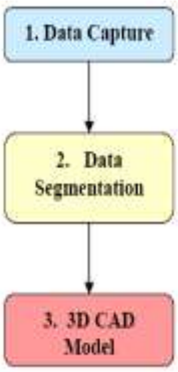

Figure 1.1: Flowchart for basic transformation phases of reverse engineering

3.1 Data Acquisition Methods

Non-contact Methods Tactile Contact Methods

Magnetic Acoustic Optical

Laser

Triangulation

CMMs Robotic Arms

Stereo Analysis

Time-of-Flight

Structured Lighting

Interferometers

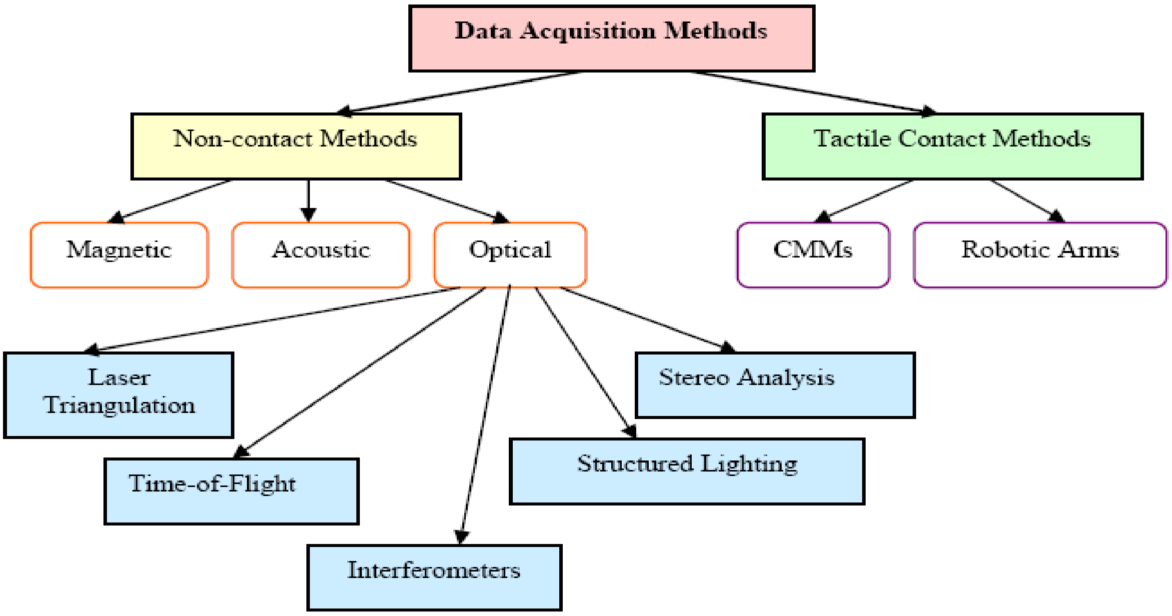

Figure 3.1: Classification of data acquisition techniques used in contact and noncontact approaches for reverse engineering systems

3.2 Contact Data Acquisition Techniques

There are many different methods for acquiring shape data, as shown in Figure 2.1.Tactile methods represent a popular approach to shape capture. The two most commonly known forms are Coordinate Measuring Machines (CMMs) and mechanical or robotic arms with a touch probe sensing device. CMMs are often used when high precision is required. It is considered a contact type method that is NC-driven and can program sampling of points for predefined features efficiently. These machines can be programmed to follow paths along a surface and collect very accurate, nearly noise-free data. Sampling basis is the only way a part can be inspected using a CMM. The ability for obtaining large amounts of point data from the parts surface quickly for complete inspection needs to be the number one quality of an inspection device. This needs to be done in conjunction with the idea that the part has free-forming surfaces. A 3-axis milling machine is an example of a mechanical or robotic arm. These machines can be fitted withal touch probe, as mentioned before, and used as a tactile measuring system. However, it's not very effective for concave surfaces. There are many different other robotic devices which are used because of their ability to have less noise and have a desirable accuracy, but like the CMM, they are the slowest method for data acquisition.

There are disadvantages when using a CMM or robotic arm to model surfaces of parts. The disadvantages of CMMs having contact to the surface of an object can damage the object. The reason being is if the surface texture is soft, holes can be inflicted on the surface. CMMs also show difficulties in measuring parts with free form surfaces. The part might have indentions that are too small. Flexibility of parts makes it very difficult to contact the surface with a touch probe without creating an indentation that detracts from the accuracy of the measurements. For CMM, geometric complexity increases the number of points required for accurate measurements. The time needed to capture points one by one can range from days or sometimes weeks for complicated parts. There are also external factors that affect the accuracy of a CMM. The main ones are temperature, vibration and humidity. Xiong gives an in depth discussion of measurement and profile error in tactile measurement. Shoo and Menq use tactile systems for sensing complex sculptured surfaces. Butler provides a comparison of tactile methods and their performance.

3.3Reverse Engineering Applying Contact Techniques

Reverse engineering is a growing industrial market for manufacturing and development. Various individuals and groups have developed new techniques, which have been improvements to the current existing techniques available. The first technique and method we visit is that of Thompson at el., their research describes a prototype of a reverse engineering system which uses manufacturing features as geometric primitives for mechanical parts. Their method is geared toward reverse engineering of mechanical parts. They have identified a feature based approach that they state produces highly accurate models, even when the original 3D sensor data has substantial errors. In the feature based approach, the registration of two different point clouds is performed by matching three points to three points, three spheres to three spheres, or three planes to three planes [28].Their main innovation was to use the features to fit scanned data, rather than using triangulated meshes or parametric surfaces patches. This research claims to have advantages over the current practice of ordinary CMMs. It states the resulting models cane directly imported into featured-based CAD systems without loss of the semantics and topological information inherent in featured-based representations. It assumes that the models are already generated into CAD model formation. The results from Thompson et al., [28] for quantitatively evaluating the accuracy of the models using the feature-based modeling approach, parts were used only if they had the original CAD model. The part was machined out of aluminum using a 3-axis NC mill. Anon-contact digitizer measured the surface points. New CAD models were generated using the REFAB (**R**everse **E**ngineering – **F**e**a**ture-**B**ased) system. The system designs model composed of mechanical features from a set of 3D surface points that could be defined by users. The geometric differences between the original and new generated

Model was computed. Further details and results from their work can be read in reference the second technique we visit is that of Yu Zhang. This research focuses on the engineering application of reverse engineering. The system employed is built with coordinate measurement machine and CAD/CAM software. By scanning the physical object, the measurement data is acquired. The basic principles of reverse engineering was applied to the design and manufacturing of the die of a diesel engine. The process described in the paper is the object digitization and CAD model reconstruction to NC machining.

The die's geometric shape is measured and data is acquired using a CMM in conjunction with KUM measurement software that has a linear scan mode. The number of points measured is determined automatically by the CMM according to the curvature change of the surface. This is measured on the tactile point. The CMM that is used can measure about 1600 points for each scanned curve. Usually a machining tracing process results in a structured point of sequences with large number of points and a line structure. The result of Zhang's system is a self developed program to realize the transformation of the format of the measured data information from the CMM and KUM. First, the format of the measured data is transformed into an acceptable format for the software used. Then the data is filtered outland processed in a visualized way. The processed data is directly used for the creation of the die CAD model. After the CAD model of the die is complete, the NC machining process planning can generate the location for cutting the manufacturing application. The die is finally machined by the NC machine tool using the created CAD model.

3.4 Non-Contact Data Acquisition Techniques

Non-contact methods use light, sound or magnetic fields to acquire shape from objects. In the case of contact and non-contact, an appropriate analysis must be performed to determine the positions of the points on the objects surface. Each method has strengths and weaknesses that require the data acquisition system to be carefully selected for the shape capture functionality desired. *Optical methods* of shape capture are probably the broadest and growing in popularity over contact methods. This is because they have relatively fast acquisition rates. There are five important categories of optical methods: laser triangulation, time-of-flight, interferometers, structured lighting and stereo analysis. This section will discuss the various principles of each method.

Laser Triangulation is a method, which uses location and angles between light sources and photo sensing devices to deduce position. A high-energy light source is focused and projected at a pre-specified angle at the surface of interest. A photosensitive device, usually a video camera, senses the reflection of the surface and then by using geometric triangulation from the known angle and distances, the position of a surface point relative to a reference plane can be calculated. The light source and the camera can be mounted on a traveling platform which then produces multiple scans of the surface. These scans are therefore relative measurements of the surface of interest. Various different high energy light sources are used, but lasers are the most common.


3.2 Laser digitalization

Triangulation can acquire data at very fast rates. The accuracy is determined by the resolution of the photosensitive device and the distance between the surface and the scanner. Montevallo et al., presents a reverse engineering strategy using laser triangulation. Moss et al., present a detailed discussion of a classic laser triangulation system used to capture shape data from facial surfaces. The use of laser triangulation on coordinate measuring machine is presented by Modjarred. These references give abroad survey of methods, approaches and limitations of triangulation. Measuring distance by sensing *time-of-flight* of the light beams emitted is the way a*rranging* system works. Practical methods are usually based on lasers and pulsating beams. For example, in laser range finders, the time-of-flight is used to determine the distance traveled, and in stereo analysis the relative locations of landmarks in multiple images are related to position. *Interferometer* methods measure the distance in terms of wavelengths using interference patterns. This can be a very accurate method of Measurement since visible light has a wavelength of the order of hundreds of nanometers, while most reverse engineering applications distances are in the centimeter to meter range. In principle, other parts of the electromagnetic spectrum could also be used. In practice, a high-energy light source is used to provide both a beam of monochromatic light to probe the object and a reference beam for comparison with the reflected light. Moring et al., describe a range finder based on time-of-flight calculations. The article presents some information on accuracy and performance. Jarvis presents an on-depth article on time-of- flight range finders giving detailed results and analysis.

Structured lighting involves projecting patterns of light upon a surface of interest and capturing an image of the resulting pattern as reflected by the surface. The image must be analyzed to determine coordinates of data points on the surface. A popular method of structured lighting is shadow Moiré, where an interference pattern is projected onto a surface producing lighted contour lines. These contour lines are captured in animate and are analyzed to determine distances between the lines. This distance is proportional to the height of the surface at the point of interest and so the coordinates of surface points can be deduced. Structured lighting can acquire large amounts of data withal single image frame, but the analysis to determine positions of data can be rather complex. Will and Pennington use grids projected onto the surface of objects to determine point locations. Wang and Agawam use a similar approach but use stripes of light and multiple images.

The final optical shape capture method of interest is *stereo image analysis*. This is similar to structured lighting methods in that frames are analyzed to determine coordinate data. However, the analysis does not rely on projected patterns. Instead, typically, stereo pairs are used to provide enough information to determine height and coordinate position. This method is often referred to as a passive method since no structured lighting is used. Active methods are distinguished from passive methods in that artificial light is used in the acquisition of data. Correlation of image pairs and landmarks within the images are big difficulties with this method and this is why active methods are preferred. Another stereo image analysis approach deals with lighting models, where an image is compared to a 3D model. The model is modified until the shaded images match the real images of the object of interest. Finally, intensity patterns within images can be used to determine coordinate information.

The final types of data acquisition methods we will examine are *acoustic*, where sound is reflected from a surface, *magnetic*, where a magnetic field touches the surface and hybrid of both contact and non-contact. Acoustic methods have been used for decades for distance measuring. Sonar is used extensively for this purpose. Automatic focus cameras often use acoustic methods to determine range. The method is essentially the same as time-of-flight, where a sound source is reflected off a surface and then distance between the source and surface is determined knowing the speed of sound. Acoustic interference or noise is often a problem as well as determining focused point locations. Dynamic imaging is used extensively in ultra-sound devices where a transducer can sweep a cross section through an object to capture material data internal to an object.

Magnetic field measurement involves sensing the strength of a magnetic field source. Magnetic touch probes are used which usually sense the location and orientation of stylus within the field. A trigger allows the user to only record specific point data once the stylus is positioned at a point of interest. Magnetic resonance is used in similar applications to ultra-sound when internal material properties are to be measured. MRI (magnetic resonance) activates atoms in the material to be measured and then measures the response.

Hybrid modeling systems are a combination of contact and non-contact systems. They can also be a combination of NC coding and laser scanning techniques. The first type usually consists of the coordinate measuring machine and integrated laser based technology. The second may consist of some other form of a non-contact technique such as software and laser-based technology integrated as one system. Hybrid based applications will be discussed in the next section.

3.5 Reverse Engineering Applying Non-Contact and Hybrid Techniques

The first hybrid-based technique reviewed is that explored by Jim Clark. The technique focuses on modelling complex and free-form shapes of mechanical objects by comparing contact and non-contact methods for digitizing the surface. A hybrid triangulation based hand held system integrated with a coordinate measuring machine is used for this approach.

The effects of ambient lighting are discussed for non-contact systems. Whether or not the system can measure the ambient lighting depends on the projected colour of light on the object. Clark summaries by writing that if a system projects laser light then the unwanted frequencies can be filtered out. If the system projects white light, then no particular frequencies can be blocked out. This is because it might be carrying the information required to measure the object. Therefore, white light area based systems will be limited in their ability to measure ambient lighting verses laser based systems. The results from Clark are of that modelled using a water pump. The water pump was scanned using both a contact and non-contact system. The results were compared based on the surface quality and the point cloud data obtained. He demonstrates that noncontact

Techniques in conjunction with advanced surfacing and inspection software yield sufficient results for the mechanical design process. Further reading of his work can be viewed in reference

Chow et al. developed an integrated laser-based reverse engineering and CAM machining system called RECSI (**R**everse **E**ngineering and **C**AM **S**ystem **I**ntegration).

4. APPLICATIONS

There are two parts to any reverse engineering application; scanning and data manipulation. Scanning also called digitizing, is the process of gathering the requisite data frogman object. Many different technologies are used to collect 3D data. They range from mechanical and very slow, to radiation based and highly automated. Each technology has its advantages and disadvantages, and their application and specifications overlap. What eventually comes out of?

Each data collection devices; however is a description of the physical object in 3D space called point cloud. Point cloud data typically define numerous points on the surface of the object inters of x, y and z coordinates. At each x, y, z coordinate in the data where there is a point, there Isa surface coordinate of the original object. However, some scanners, such as those based on rays, can see inside an object. In that case, the point cloud also defines interior locations of the object, and may also describe its density.

4.1 Typical RE Applications

1. Creating data to refurbish or manufacture a part for which there is no CAD data, or for which the data has become obsolete or lost.
2. Inspection and/or quality control- comprising a fabricated part to its CAD description or to a standard item.
3. Creating 3D data from a model or sculpture for animation in games and movies.
4. Creating 3D data from an individual model or sculpture for creating, scaling or reproducing Art work.
5. Documentation and /or measurement of cultural objects or artifacts in archaeology, paleontology and scientific fields.
6. Fitting clothing or footwear to individuals and determining the anthropometry's of a population.
7. Generating data to create dental or surgical prosthetics, tissue-engineered body parts or for surgical planning.
8. Documentation and reproduction of crime scenes.
9. Architectural and construction documentation and measurement.

5. CONCLUSION

The methodology presented in this paper consist in 3D scanning of a real object, processing of the scanned results by reverse engineering and obtaining a digital geometric model and conducting numerical analysis. This methodology can by successfully applied in design optimization, especially in objects with complex geometry In industrial manufacturing, tolerance assignment is one of the key activities in the product creation process. However, tolerance is much more difficult to be successfully handled in RE. In this case all or almost all of the original component design and manufacturing information is not available and the dimensional and geometric accuracy specifications for component reconstruction have to be re-established, one way or the other, practically from scratch. RE-tolerance includes a wide range of frequently met industrial manufacturing problems and is a task that requires increased effort, cost and time, whereas the results, usually obtained by trial-and-error, may well be not the best. The proposed methodology offers a systematic solution for this problem in reasonable computing time and provides realistic and industry approved results. This research work further extends the published research on this area by focusing on type of tolerances that are widely used in industry and almost always present in reverse engineering applications. The approach, to the extent of the author's knowledge, is the first of the kind for this type of RE problems that can be directly implemented within a CAD environment. It can also be considered as a pilot for further research and development in the area of RE tolerance. Future work is oriented towards the computational implementation of the methodology in 3D-CAD environment, the RE *composite* position tolerance that concerns patterns of repetitive features, the methodology application on the whole range of GD&T types and the integration of function oriented wear simulation models in order to evaluate input data that come from RE parts that bear considerable amount of wear.

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