

Introduction to Reverse Engineering

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Abstract

This chapter introduces readers to the term reverse engineering (RE), and to the associated techniques that can be used for scanning physical parts. In addition, the chapter presents the process of reverse engineering and the strategy for scanning and converting the scanned data into a 3-D surface or solid model.

1.1 Introduction

In today's intensely competitive global market, product enterprises are constantly seeking new ways to shorten lead times for new product developments that meet all customer expectations. In general, product enterprise has invested

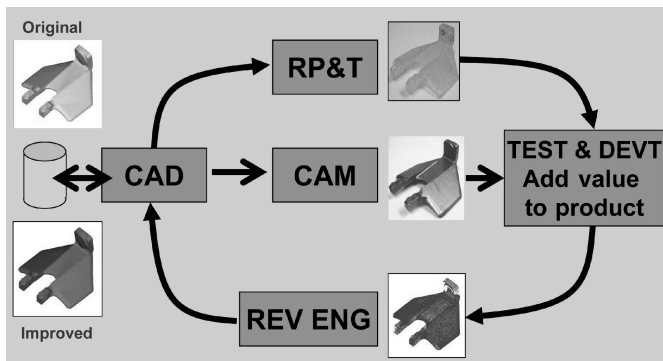


Figure 1.1. Product development cycle

in CAD/CAM, rapid prototyping, and a range of new technologies that provide business benefits. Reverse engineering (RE) is now considered one of the technologies that provide business benefits in shortening the product development cycle. Figure 1.1 below depicts how RE allows the possibilities of closing the loop between what is “as designed” and what is “actually manufactured”.

1.2 What Is Reverse Engineering?

Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems. There are two types of engineering, forward engineering and reverse engineering. Forward engineering is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system. In some situations, there may be a physical part/product without any technical details, such as drawings, bills-of-material, or without engineering data. The process of duplicating an existing part, subassembly, or product, without 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 3-D points acquired by scanning/digitizing existing parts/products. The process of digitally capturing the physical entities of a component, referred to as reverse engineering (RE), is often defined by researchers with respect to their specific task (Motavalli & Shamsaasef 1996). Abella *et al.* (1994) described RE as, “the basic concept of producing a part based on an original or physical model without the use of an engineering drawing”. 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”.

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 software engineering, good source code is often a variation of other good source code. 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.

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 physical-to-digital process depicted in Figure 1.2. Another reason for reverse engineering is to compress product development cycle 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 shortened product development time. For example, injection-molding companies need to shorten tool and die

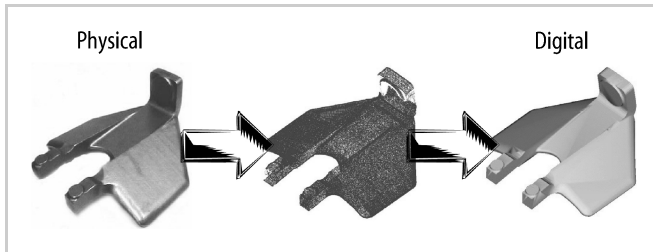


Figure 1.2. Physical-to-digital process

development time drastically. By using reverse engineering, a three-dimensional physical product or clay mock-up can be quickly captured in the digital form, remodeled, and exported for rapid prototyping/tooling or rapid manufacturing using multi-axis CNC machining techniques.

1.3 Why Use Reverse Engineering?

Following are some of the reasons for using reverse engineering:

- The original manufacturer no longer exists, but a customer needs the product, *e.g.*, aircraft spares required typically after an aircraft has been in service for several years.
- The original manufacturer of a product no longer produces the product, *e.g.*, the original product has become obsolete.
- The original product design documentation has been lost or never existed.
- Creating data to refurbish or manufacture a part for which there are no CAD data, or for which the data have become obsolete or lost.
- Inspection and/or Quality Control—Comparing a fabricated part to its CAD description or to a standard item.
- Some bad features of a product need to be eliminated *e.g.*, excessive wear might indicate where a product should be improved.
- Strengthening the good features of a product based on long-term usage.
- Analyzing the good and bad features of competitors' products.
- Exploring new avenues to improve product performance and features.
- Creating 3-D data from a model or sculpture for animation in games and movies.
- Creating 3-D data from an individual, model or sculpture to create, scale, or reproduce artwork.
- Architectural and construction documentation and measurement.
- Fitting clothing or footwear to individuals and determining the anthropometry of a population.

- Generating data to create dental or surgical prosthetics, tissue engineered body parts, or for surgical planning.
- Documentation and reproduction of crime scenes.

The above list is not exhaustive and there are many more reasons for using reverse engineering, than documented above.

1.4 Reverse Engineering–The Generic Process

The generic process of reverse engineering is a three-phase process as depicted in Figure 1.3. The three phases are scanning, point processing, and application-specific geometric model development. Reverse engineering strategy must consider the following:

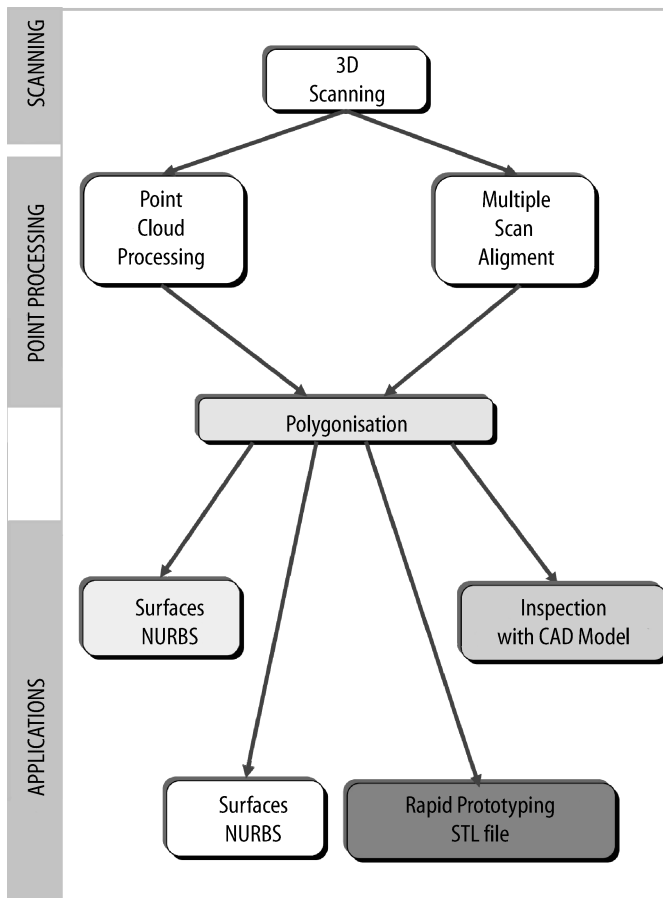


Figure 1.3. Reverse engineering – the generic process

- Reason for reverse engineering a part
- Number of parts to be scanned–single or multiple
- Part size–large or small
- Part complexity–simple or complex
- Part material–hard or soft
- Part finish–shiny or dull
- Part geometry–organic or prismatic and internal or external
- Accuracy required–linear or volumetric

1.5 Phase 1–Scanning

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.

1.5.1 Contact Scanners

These devices employ contact probes that automatically follow the contours of a physical surface (Figure 1.4). In the current marketplace, contact probe

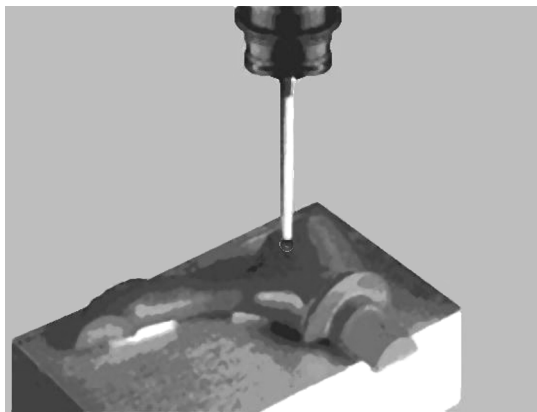


Figure 1.4. Contact scanning touch probe. Originally published in *Rapid Prototyping Casebook*, McDonald, J.A., Ryal, C.J. and Wimpenny, D.I., 2001, © John Wiley and Sons Limited. Reproduced with permission.

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.

1.5.2 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 1.5. 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 1.6).
- 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.

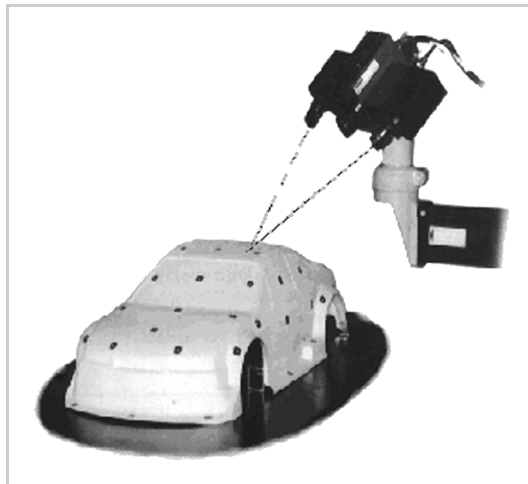


Figure 1.5. Optical scanning device. Originally published in *Rapid Prototyping Casebook*, McDonald, J.A., Ryal, C.J. and Wimpenny, D.I., 2001, © John Wiley and Sons Limited. Reproduced with permission.

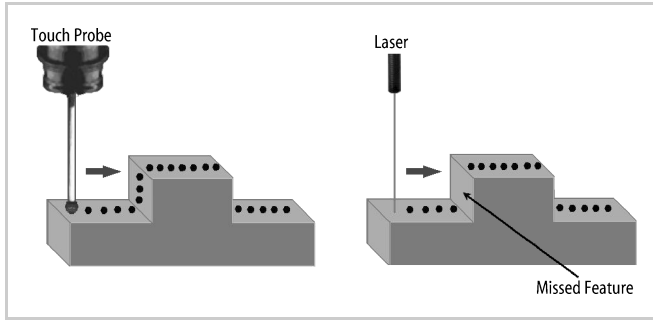


Figure 1.6. Vertical faces—touch probe versus a laser. Originally published in *Rapid Prototyping Casebook*, McDonald, J.A., Ryal, C.J. and Wimpenny, D.I., 2001, © John Wiley and Sons Limited. Reproduced with permission.

These issues restrict the use of remote sensing devices to areas in engineering, where the accuracy of the information generated is secondary to the speed of data capture. However, as research and laser development in optical technology continue, the accuracy of the commercially available noncontact scanning device is beginning to improve.

The output of the scanning phase is point cloud data sets in the most convenient format. Typically, the RE software provides a variety of output formats such as raw (X, Y, Z values separated by space or commas).

1.6 Phase 2–Point Processing

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. It is extremely important that the users have very good understanding of the filter algorithms so that they know which filter is the most appropriate for each task. 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. Good datum planning for multiple scanning will reduce the effort required in the point processing phase and also avoid introduction of errors from merging multiple scan data. A wide range of commercial software is available for point processing.

The output of the point processing phase is a clean, merged, point cloud data set in the most convenient format. This phase also supports most of the proprietary formats mentioned above in the scanning phase.

1.7 Phase 3—Application Geometric Model Development

In the same way that developments in rapid prototyping and tooling technologies are helping to shorten dramatically the time taken to generate physical representations from CAD models, current RE technologies are helping to reduce the time to create electronic CAD models from existing physical representations. The need to generate CAD information from physical components will arise frequently throughout any product introduction process.

The generation of CAD models from point 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.

The applications of RE for generating CAD data are equally as important as the technology which supports it. A manager's decision to employ RE technologies should be based on specific business needs.

This phase depends very much on the real purpose for reverse engineering. For example, if we scanned a broken injection molding tool to produce a new tool, we would be interested in the geometric model and also in the ISO G code data that can be used to produce a replacement tool in the shortest possible time using a multi-axis CNC machine. One can also use reverse engineering to analyze “as designed” to “as manufactured”. This involves importing the as designed CAD model and superimposing the scanned point cloud data set of the manufactured part. The RE software allows the user to compare the two data sets (as designed to as manufactured). This process is also used for inspecting manufactured parts. Reverse engineering can also be used to scan existing hip joints and to design new artificial hips joint around patient- specific pelvic data. This creates the opportunity for customized artificial joints for each patient.

The output of this phase is geometric model in one of the proprietary formats such as IGES, VDA, STL, DXF, OBJ, VRML, ISO G Code, *etc.*

This chapter defined the term “reverse engineering” followed by reasons for using reverse engineering. It also introduced the reverse engineering strategy, the three phases of the reverse engineering generic process, contact and noncontact scanning, point processing, and application geometric model development.

Chapter 2 builds on Chapter 1 by providing an in-depth depiction of methodologies and techniques for reverse engineering.

Chapter 3 presents information on reverse engineering hardware and software and also provides excellent information on commercially available reverse engineering hardware and software.

Chapter 4 provides a structured approach for selecting the appropriate reverse engineering system for a specific business need.

Chapter 5 introduces the fundamentals of rapid prototyping with an in-depth description of various commercially available rapid prototyping technologies.

Chapter 6 provides excellent information on the relationship between reverse engineering and rapid prototyping.

Chapter 7 provides cases studies of successful applications of reverse engineering in the automotive industry.

Chapter 8 provides cases studies of successful applications of reverse engineering in the aerospace industry.

Chapter 9 provides cases studies of successful applications of reverse engineering in the medical equipment industry.

Chapter 10 describes the legal aspects and implications of reverse engineering.

Chapter 11 discusses the barriers to adopting reverse engineering.



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