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RE (reverse engineering) as necessary phase by rapid product development

M. Sokovic*, J. Kopac

Faculty of Mechanical Engineering, University of Ljubljana, Askerceva 6, SI-1000 Ljubljana, Slovenia

Abstract

The engineering design supported by CAD/CAE techniques allows optimising the product concept before manufacturing with assistance of CAM, in management for rapid product development and rapid set-up production in advance. For some product development processes reverse engineering (RE) allows to generate surface models by three-dimensional (3D)-scanning technique, and consequently this methodology permits to manufacture different parts (for cars, for household appliances) and tools (moulds, dies, press tools) in a short development period. The aim of this paper is to present a brief overview of RE as a necessary phase which provide benefits to the design and production processes in advance.

Keywords: Scanning (digitising); Reverse engineering; Product design; Rapid prototyping; CAD/CAE/CAM techniques

1. Introduction

Why rapid product development is necessary, asked many workers special in countries of middle and east Europe. Owners and directors of factories answer is, that the involved money in process must give maximal benefit in other case they not make investment in such production. Very important production is cars manufacturing, where every of car content thousand and more pieces, which must be made as quicker and chipper is possible, by achieving of prescribed quality.

By small or bigger changing of car model there are changing many of pieces too. The time of changing became shorter and shorter and requirements push all in the production chain in great hurry with time. In this case are very useful and successful the methods of reverse engineering (RE). The very important tools, which help in this process, are different scanning systems, which ensure in the short time exact dimensional description in digital concept, which is useful for direct control on machine tool in advance. We can add or change some shapes, dimensions or some functional matters and prepare CNC-code for new article [1,2].

The RE is now an accepted part of contemporary product design and manufacturing process. The RE process can be loosely defined as process that result in the creation of a mathematical model from a physical one. There are some reasons why this is necessary:

- Some parts exist for which no design/manufacturing documentation exists.
- In some cases it is necessary only to extract 2D profile data from the model as the complete part may be efficiently modelled using these profiles and a surface/solid CAD/CAM system.
- Potential application area can be found in the injection moulding industry (rapid tooling, recovering broken moulds or duplicating a mould); other fields such as medical, eyewear or the toy industry [3].

All the above-cited cases have very different RE requirements; from recovering mechanical design information to design based modifications. In the case of extracting mechanical design information, we will be interested in absolute tolerance contrary to the case of design based extraction where the precedent will be that of extracting design intent. In mentioned contest, the RE methodologies and techniques are absolutely necessary because allows capturing

* Corresponding author.
E-mail address: mirko.sokovic@fs.uni-lj.si (M. Sokovic).

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and digitising the object surface geometry to be utilised in CAD/CAE/CAM.

2. Product development approaches

Nowadays the management of engineering product design could be realised based on the two methodologies presented in Fig. 1, trough two information flows called "conventional approach" and "non-conventional approach" [4].

2.1. Conventional approach

The conventional approach to develop products with CAD/CAE/CAM techniques normally starts with the geometric modelling utilising a CAD system. The geometric model could be represented as a wire frame or as surfaces or as a solid structure.

Via conceptual modelling, the generated CAD information could be exported subsequently in standard format (IGES points/STL binary, ASCII data, DXF polyline, VDA points or IGES/STL surfaces) and imported in the same data format to CAE systems (allowing numerical model simulation) and/or to CAM systems (allowing to generate tooling trajectories—NC-code). In a system with a unique database, the design information could be shared between every application automatically, without the need to transfer data manually, each time.

2.2. Non-conventional approach

The product development by conventional approach is not applicable when the goal is to reengineer or to simulate and to optimise parts/moulds/tools already existents without information in CAD data format. Consequently, will be necessary to apply techniques that allow capturing the geometry of parts/moulds/tools (or prototypes), and to generate a conceptual numerical model that will be used in CAE and CAM systems. This process is regularly called reverse engineering [2–4].

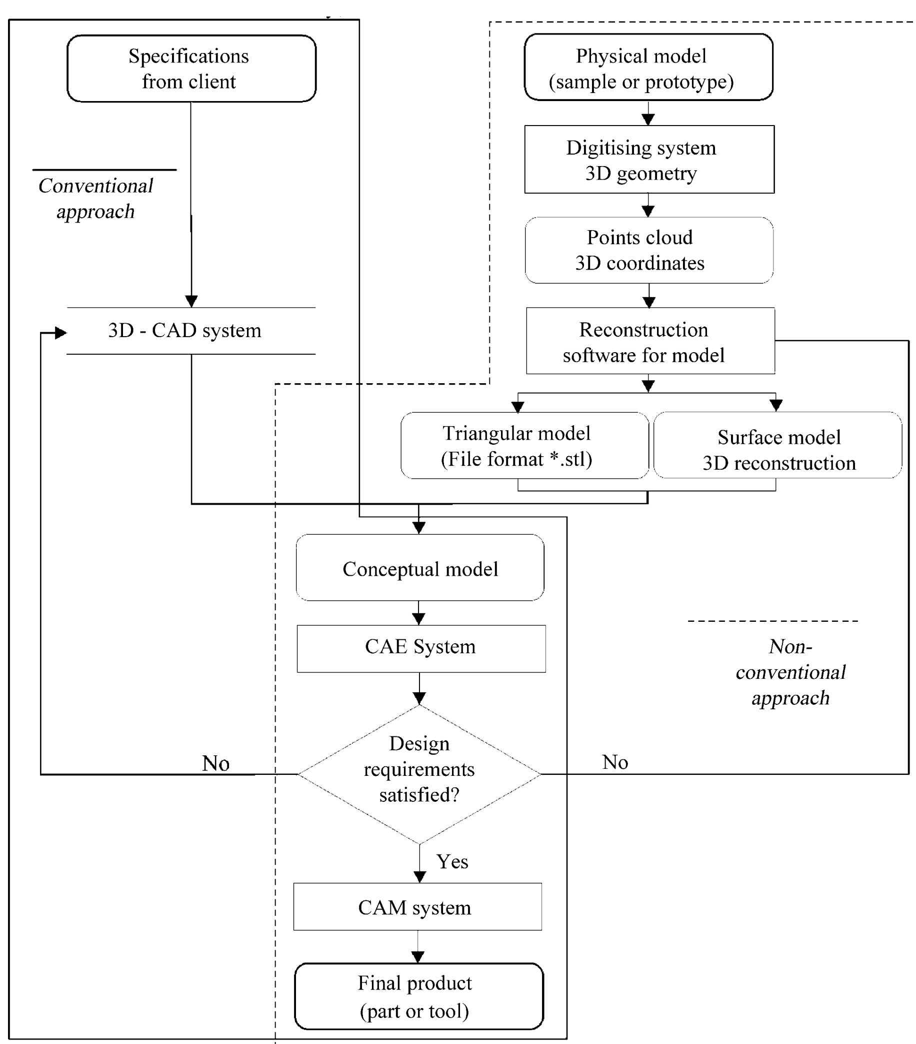

Fig. 1. Sequences to manufacture engineering products (parts/moulds/tools).

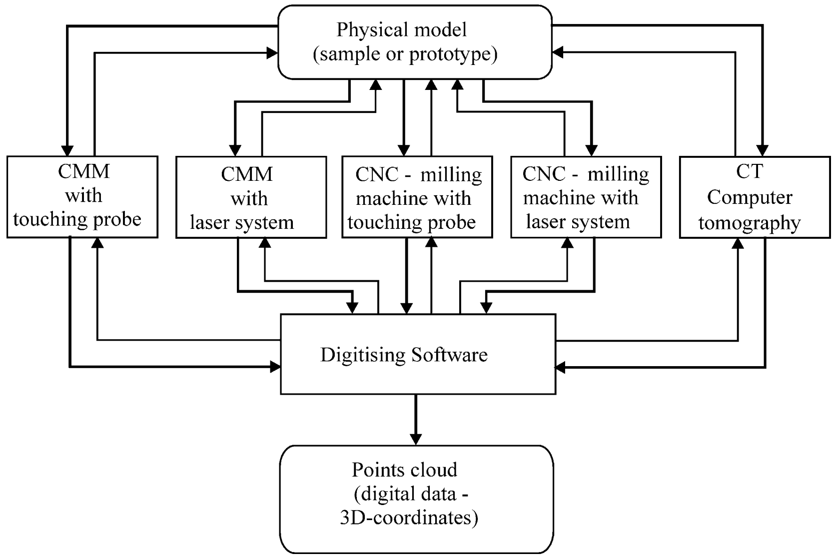

Fig. 2. Digitising techniques for the 3D-geometries and generated data.

3. The reverse engineering process

The RE process can be divided into three steps:

- digitising;
- data segmentation;
- data fitting.

The first objective of RE methodology is to generate a conceptual model (example: surface triangulated) from a physical model: a sample (part or tool) or prototype. In this sense the 3D-scanning (digitising) techniques aided by specialised software's for model reconstruction are necessary.

3D-scanning (digitising) is the process of gathering data from an undefined three-dimensional surface. During the scanning process, an analogue-scanning probe is commanded to move back and forth (contact or non-contact) across the unknown surface. During this process, the system records information about the surface in the form of numerical data—generates a point's cloud matrix (3D-coordinates). This data may then be used to create a CNC-program to machine a replica or geometric variant of the shape.

Alternatively, the data can be exported in various formats to a CAD/CAM system for further processing [2,5].

When digitising a part at least the following factors must be taken into consideration [3]:

- What is the model made of?
- What is the physical condition of the model?
- Need for fixtures.
- Alignment requirements.
- Digitiser errors.
- Available digitisers.
- What is the required use of the resultant geometric model?

Of these factors the last one is probably the most important and in many cases not taken sufficiently into consideration.

3.1. Difference between digitising and scanning

The terms digitising and scanning are often used to describe the same process. Traditionally, the term digitising referred to the process of taking discrete points from a surface using a touch-trigger probe. However, with the introduction of new technologies in data capture such as laser, camera, vision and analogue probe systems, the term digitising is now used as the generic description for the process of acquiring data from undefined surfaces [5,6].

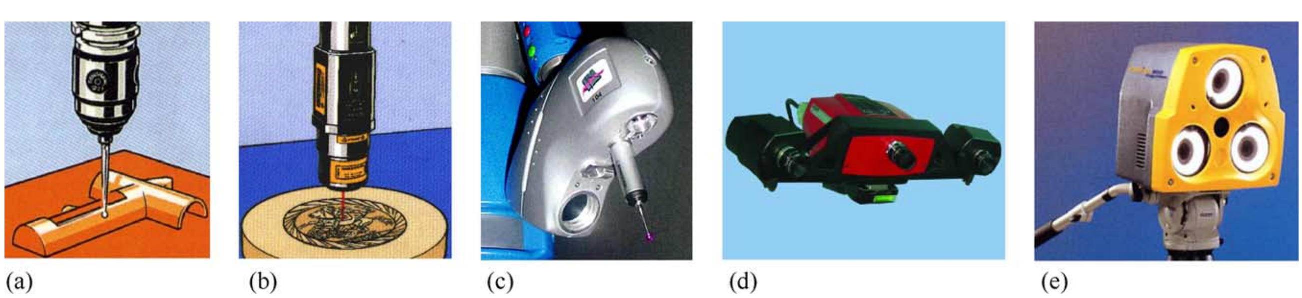

Fig. 3. Different probe sensors for digitising equipments: (a) physical touching probe sensor, (b) laser beam probe and (c–e) optical sensors (CCD cameras).

The digital points cloud could be captured from different digitising techniques (Fig. 2), classified in two main groups:

- The mechanical techniques (by physical contact sensors).
- The optical techniques (by non-contact with the object).

Related with the first group is normally utilised a coordinate measuring machine (CMM), or a CNC-milling machine basis, equipped with physical touching probe sensors (i.e. Retroscan or Renscan—Renishaw, UK), Fig. 3a.

Related with the second group, could be utilised also a CMM or a CNC-milling machine basis, but equipped with laser beam probes Renishaw (Fig. 3b), Metris LC Mitutoyo, Comet T-Scan Steinbichler—Germany or associated to optical sensors (ex. CCD-cameras), Kréon—France (Fig. 3c), ATOS II GOM mbH—Germany (Fig. 3d), Optigo 200 CogniTens—Israel, for non-contact coordinate measuring (Fig. 3e). For the second group would be also exist techniques utilising computer tomography (CT) that allows to capture also the inside object geometry [6].

Possibilities of use RE-methodology

Product design
- RP (Rapid Prototyping)
- Digital mock-up

Tool making
- Mould, die, press tool
- EDM electrode prototype

Rapid production
- car parts
- household appliances…

CAE
- Numerical simulation and optimisation of product

Fig. 5. Possibilities of use RE-methodology.

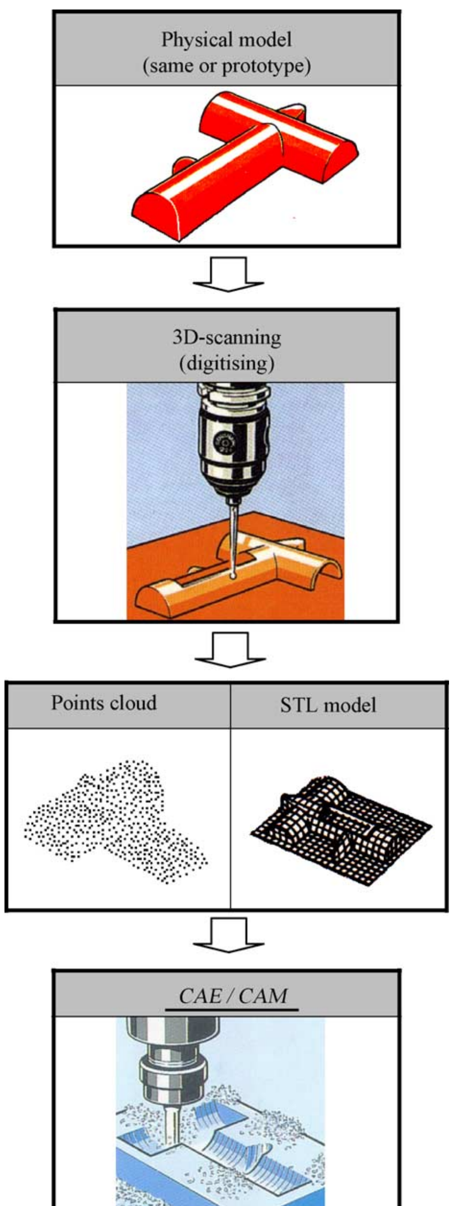

Fig. 4. Example of the sequences of the reverse engineering (RE), corresponding to Fig. 1.

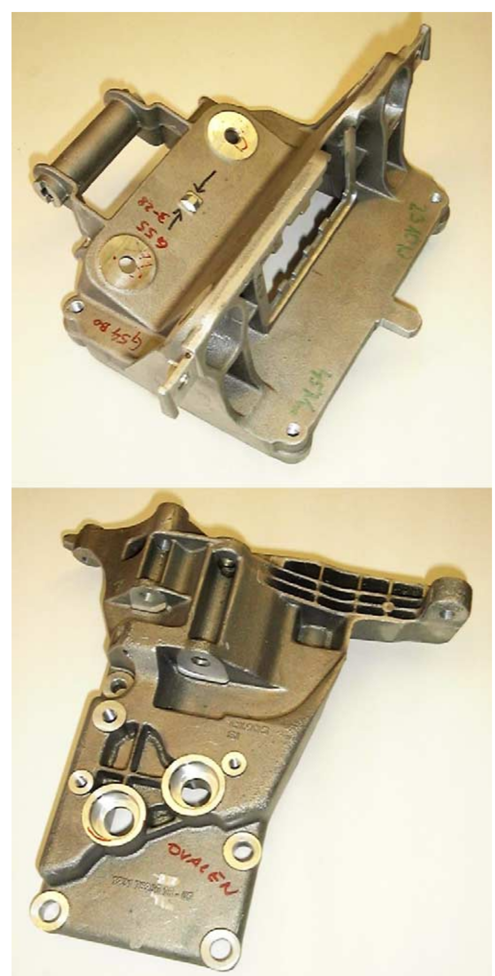

Fig. 6. Examples of manufactured prototypes of car parts in the second phase of R&D process [1].

Table 1
Review of the advantages and weaknesses of different scanning systems

Type of scanning	Advantages	Weaknesses
CCD cameras	Fast	High price of equipment
	It is possible to use two or three cameras simultaneously	Accuracy decreases linear depend of the camera distance
	Insensible to colour of parts (additional SW-controlled light)	Scanning angle is equal regardless of the shape of the parts surface; in the case of very steep angles the measurement is very disfigured
	Non-contact method; it is possible to scan of soft materials	By scanning with camera very high sharpness of visible picture is required; simultaneous scanning of close and far surface details demonstrates linear deviation of the results respect to different focus distance
	In the case of special coaxial lightening it is possible to scan small diameters and high depths in the *Z*-axis	In the case of oily of wet parts scanning the results are disfigured
	It is possible to scan very small areas, cca 1 mm^2 (one scan is enough)—accuracy is about some micrometers	Dust causes fault by scanning
	Scanning of the flat surfaces is very fast (principle of the profile projector)	
Laser	Precise and fast scanning in *Z*-axis (0.001 mm or better)	Very high price of equipment
	Non-contact method	It is not possible to scan reflective materials
	It is possible to scan of soft materials (also liquids)	Scanning in *X*- and *Y*-axis is very inaccurate (0.035–0.060 mm)
		It is not possible to scan on the area of notches or very steep surfaces because of additional reflection
		Sensitivity to draught and dust in the air
Contact (classical)	Very precise in all axis (depends of the scanning equipment)	It is not appropriate to soft materials
	Very fast scanning of geometrical well-known parts	Scanning of unknown surfaces is not makes possible or process of scanning is very slow and inaccurate
	Very precise scanning of coins and similar relief	
	Possibility of manual or automatic scanning	
	Hand scanning equipment (measurement hand) is useful for scanning very big products such as: airplanes, ships, big machines and devices (accuracy of scanning is not drastically changes)	
Contact (Renishaw Cyclone 2)	Very precise in all axis (0.001 mm)	Minimum diameter of stylus is 0.3 mm; scanning of surface roughness is not possible
	Relatively low price of apparatus	Is not suitable to scan soft materials
	It is possible to use different styli for different surfaces	Although is stylus material resistant against wear, stylus surface wears after time
	It is possible to scan unknown surfaces with similar accuracy compare to known ones	Scanning speed is lower (compare to non-contact scanning systems)
	It is possible to scan unknown steep surface (angle is very close to 90°) very accurate	
	Oil, liquid and dust on the surface do not disturb scanning process	
	Scanning module works like 3D measurement device—no problem by scanning un-perpendicular surfaces	
	Scanning speed automatically adapt oneself to surface roughness—scanned values (coordinates in *X*-, *Y*- and *Z*-axes) are very accurate; direct, accurate comparison with CAD drafts is possible (resolution and accuracy are ±0.002 mm also by 350 mm long probe)	
	It is possible to use scanning SW, which is combine with appropriate controller, on the every measurement table; scanning speed is more than 20 times faster compare to classical configuration, because is not necessary to write additional program for measurement	

3.2. 3D-CAD redesign from digitising data

The data generated during 3D-scanning, i.e. the digital points cloud data in X, Y, Z coordinates, is exported to a model reconstruction system software to be transformed in a conceptual model supported by a triangular surface geometry or by a CAD-surface data (Fig. 4). When finish the conceptual model, the subsequent procedures are similar to the conventional sequence by product development that normally starts with the geometric modelling utilising a CAD-system, see Fig. 1 [2,4].

Some of important possibilities of use the RE-methodology in the practice shown in Fig. 5.

3.3. What type of sensor should be used

For most applications, the best results in terms of accuracy and quality of surface finish are obtained using contact sensors. However, where very soft and fragile materials (and non-reflective surface) is to be scanned, non-contact, laser or optical systems offers (Renishaw, "Kréon", ATOS II, Optigo, . . .).

Contact systems have several fundamental advantages over the majority of available non-contact systems, Table 1 [2,6].

An ideal scanning device would be combination of camera, laser and contact probe supported with appropriate controller.

3.4. RE for foundry parts and tools reconstruction

The use of RE methodology in the R&D study of casting parts for automotive industry allowed optimising a casting part and to manufacture the respective rapid tools for sand casting in the first step. In the second phase, it is possible to use RE for extracting mechanical design information or design based modifications. In the case of extracting mechanical design information we will be interested in absolute tolerance (Fig. 6) contrary to the case of design based extraction where the precedent will be that of extracting design intent.

4. Conclusion

The product (parts, moulds, tools) development via integrated reverse engineering is a recent methodology in research and development phase. If is today this methodology additionally integrated with new rapid manufacturing technologies such as high speed machining (HSM) and five-axis milling, allows manufacturing time reduction and associated costs for product development and management. For these production methodologies and techniques the 3D-scanning (digitising) is the initial activity to capture the product geometries.

This paper shows some possibilities of use and benefit from utilising the RE-methodologies and techniques in production process, especially in the case when exists parts without 3D-CAD support. In this contest, RE is absolutely necessary because allows capturing and digitising the object surface geometry to be utilised in CAD/CAE/CAM. In the paper is also given some interesting information about characteristics (advantages and weaknesses) of different scanning systems (contact or non-contact).

Therefore, the RE-process (integrated with the recent rapid prototyping and/or rapid tooling technologies) is granted by numerical simulation the process and product optimisation to increase the final product quality, lead to increase the competitiveness in the different cases (car parts production, production of parts for household appliance, rapid tool making for these parts).

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