



## ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

### RE (Reverse Engineering) as necessary phase by rapid product development\*

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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 RE (Reverse Engineering) allows to generate surface models by 3D-scanning technique, and consequently this methodology permits to manufacture different parts and 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.

### 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 RE (Reverse Engineering). 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 maters and prepare CNC code for new article [1].

### 2. THE REVERSE ENGINEERING 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 many 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.

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- 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 [2].

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 is the process of gathering data from an undefined 3-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 [3, 4].

**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 [4].

The digital points cloud could be captured from different digitising techniques (Fig. 1), 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 (Retroskan or Renscan - Renishaw). Related with the second group, could be utilised also a CMM or a CNC milling machine basis, but equipped with laser beam probes associated to optical sensors (ex. CCD cameras - "Kréon", ATOS II - GOM mbH, Optigo 200 – CogniTens) for non-contact coordinate measuring. For the second group also exists techniques utilising computer tomography (CT) that allows to capture also the inside object geometry.

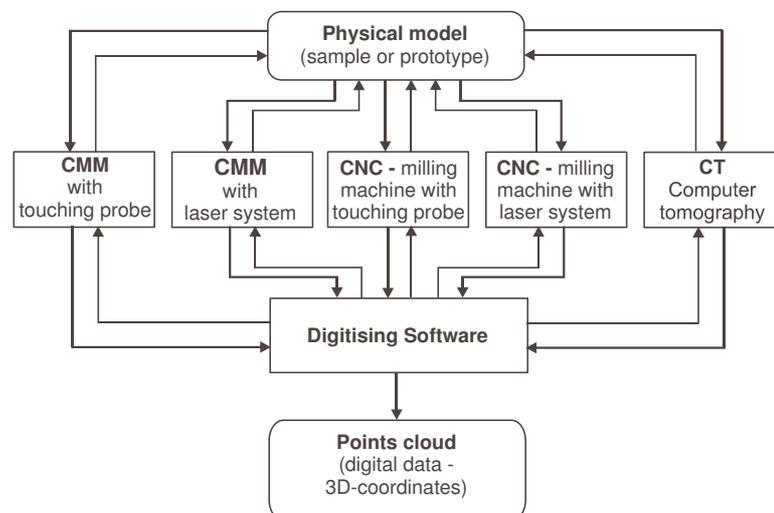


Fig. 1. Digitising techniques for the 3D-geometries and generated data

**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. 2). 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 [3].

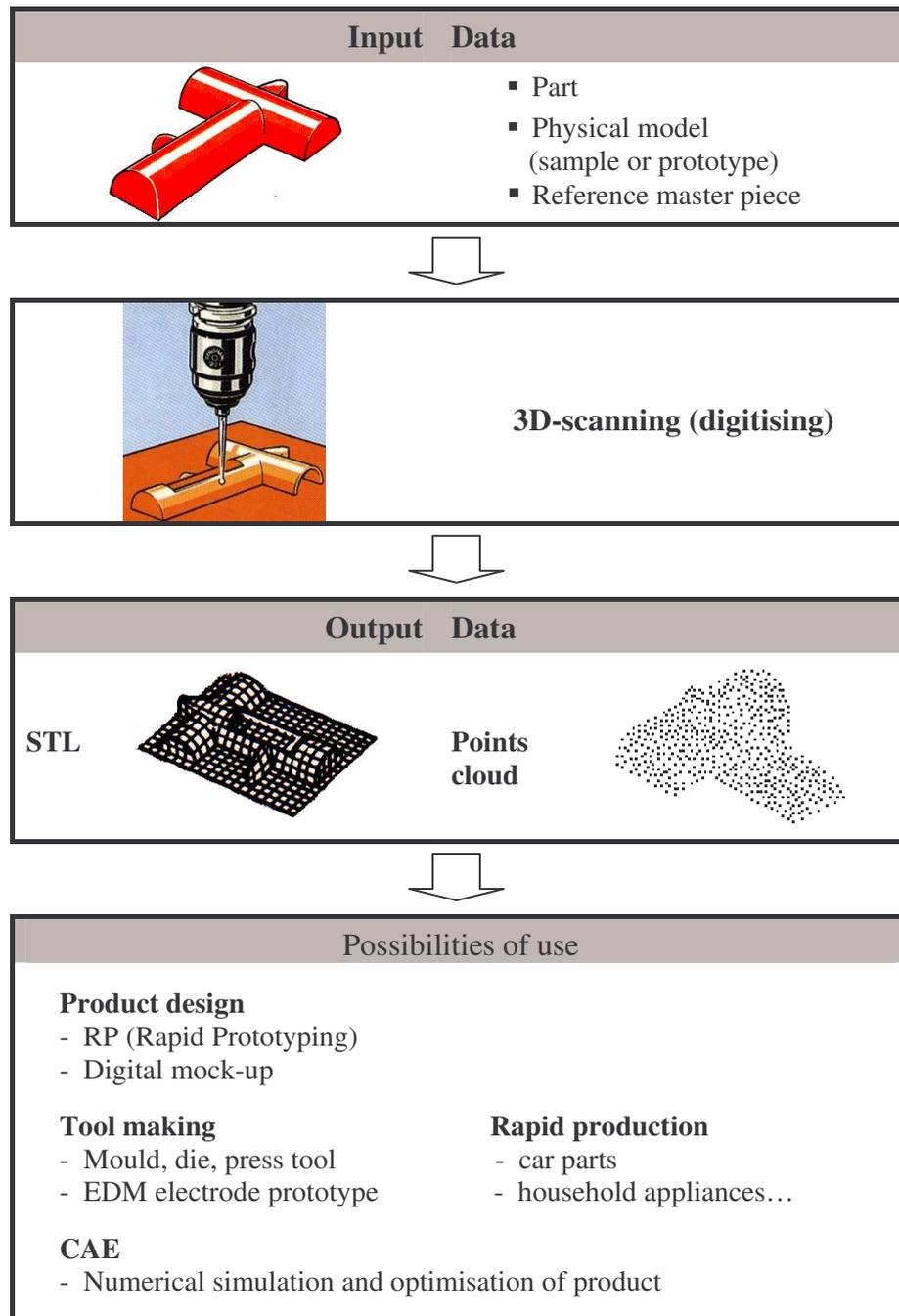


Fig. 2. Sequences of the Reverse Engineering and possibilities of use

**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) are to be scanned, non-contact, laser or optical systems offers (Renishaw, “Kréon”, ATOS II or Optigo).

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

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

| Type of scanning | Advantages  | Weaknesses  |
|------------------|---|---|
| CCD Cameras      | <ul style="list-style-type: none"> <li>• Fast</li> <li>• It is possible to use two or three cameras simultaneously</li> <li>• Insensible to colour of parts (additional SW-controlled light)</li> <li>• Non-contact method; it is possible to scan of soft materials</li> <li>• In the case of special coaxial lightening it is possible to scan small diameters and high depths in the Z-axis</li> <li>• It is possible to scan very small areas, cca 1 mm<sup>2</sup> (one scan is enough) - accuracy is about some micrometers</li> <li>• Scanning of the flat surfaces is very fast (principle of the profile projector)</li> </ul> | <ul style="list-style-type: none"> <li>• High price of equipment</li> <li>• Accuracy decreases linear depend of the camera distance               <ul style="list-style-type: none"> <li>• Scanning angle is equal regardless of the shape of the parts surface; in the case of very steep angles the measurement is very disfigured</li> </ul> </li> <li>• 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</li> <li>• In the case of oily or wet parts scanning the results are disfigured</li> <li>• Dust causes fault by scanning</li> </ul> |
| Laser            | <ul style="list-style-type: none"> <li>• Precise and fast scanning in Z-axis (0,001 mm or better)               <ul style="list-style-type: none"> <li>• Non-contact method</li> </ul> </li> <li>• It is possible to scan of soft materials (also liquids)</li> </ul>   | <ul style="list-style-type: none"> <li>• Very high price of equipment               <ul style="list-style-type: none"> <li>• It is not possible to scan reflective materials</li> </ul> </li> <li>• Scanning in X- and Y-axis is very inaccurate (0,035 - 0,060 mm)</li> <li>• It is not possible to scan on the area of notches or very steep surfaces because of additional reflection</li> <li>• Sensitivity to draught and dust in the air</li> </ul>   |

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| <p><b>Contact (classical)</b></p>          | <ul style="list-style-type: none"> <li>• Very precise in all axis (depends of the scanning equipment)</li> <li>• Very fast scanning of geometrical well-known parts</li> <li>• Very precise scanning of coins and similar relief</li> <li>• Possibility of manual or automatic scanning</li> <li>• 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)</li> </ul>  | <ul style="list-style-type: none"> <li>• It is not appropriate to soft materials</li> <li>• Scanning of unknown surfaces is not makes possible or process of scanning is very slow and inaccurate</li> </ul>   |
| <p><b>Contact (Renishaw Cyclone 2)</b></p> | <ul style="list-style-type: none"> <li>• Very precise in all axis (0,001 mm)</li> <li>• Relatively low price of apparatus</li> <li>• It is possible to use different styli for different surfaces</li> <li>• It is possible to scan unknown surfaces with similar accuracy compare to known ones</li> <li>• It is possible to scan unknown steep surface (angle is very close to 90°) very accurate</li> <li>• Oil, liquid and dust on the surface do not disturb scanning process</li> <li>• Scanning module works like 3D measurement device – no problem by scanning un-perpendicular surfaces</li> <li>• 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 <math>\pm 0,002</math> mm also by 350 mm long probe)</li> <li>• 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</li> </ul> | <ul style="list-style-type: none"> <li>• Min. diameter of stylus is 0.3 mm; scanning of surface roughness is not possible</li> <li>• Is not suitable to scan soft materials</li> <li>• Although is stylus material resistant against wear, stylus surface wears after time</li> <li>• Scanning speed is lower (compare to non-contact scanning systems)</li> </ul> |

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

### 3. CONCLUSIONS

The product (car parts, parts for household appliance) development via integrated Reverse Engineering (RE) 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 5 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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