

REVERSE ENGINEERING AND RAPID PROTOTYPING INTEGRATION

Diana POPESCU, Cristina PUPĂZĂ, Robert IACOB, Marian IVANOV

Abstract: *The integration of reverse engineering, 3D CAD modeling and rapid prototyping technologies is used more and more by companies in the world, in order to cut the time-to-market and costs for new products and thus to gain competitive advantages over the competition. The present article is setting the general approach for this type of integration and describes the main steps of a product development cycle based on this integration. The range of applications is very large and can cover not only the engineering field, but also the medical one, by improving the design and functionality of prostheses, implants or surgical tools or even architecture and arts.*

Key words: *reverse engineering, rapid prototyping, CAD modeling, integration.*

1. INTRODUCTION

The large variety of products and the necessity to gain advantages over the competition, determined the need to identify and implement the designer requirements in the early phases of the development cycle.

In the last couple of years, reverse engineering (RE), virtual and rapid prototyping (RP) techniques developed significantly, being considered important tools in decreasing the time-to-market and costs, and increasing the efficiency and overall quality of the products [1, 2].

The use of 3D CAD models (or virtual prototype) allows not only using and reusing parts information and accommodates the frequent changes, but it is also a base for Finite Element Method (FEM) analysis, simulations or ergonomic studies.

Each of these technologies has their own strengths, but there are also advantages offered by their integration. The present paper describes the main characteristics of RE and RP processes, and presents a framework for the integration. The link between RP and RE is based on the use of STereoLithography (STL) geometry data files as will be described further.

In the case study, the theoretical concepts are applied for the case of a polygonal model of a human face (free-form shape). The mesh of patches processed from WRL data is checked and edited for generating a surface model and then the solid model is obtained. In the next step, the solid model is exported in STL format for using it in a RP software – Catalyst (FDM – Fused Deposition Modeling). The general procedure of integration between RE and RP described in this example can be applied for any type of component.

2. REVERSE ENGINEERING PROCESS

In [3] reverse engineering process is defined as systematic evaluation of a product with the purpose of replication which involves either direct copies or adding improvements to existing. According to [4], reverse engineering refers to the process in which designers acquire a

design concept of a product from digitization of a physical model, and create the CAD model to realize approximation to the physical model: the model created can be reused, modified and optimized.

The RE process consists in three phases (Fig.1) [5, 6]:

- Scanning. 3D scanning devices are used for the process of gathering data (in the form of clouds of points) which define the surface. There are several digitizing technologies using: CMM with touching probe, CMM with laser system, CT computer tomography, CNC milling machine with touching probe or CNC milling machine with laser system.
- Point processing. In this stage, the point cloud data is imported and filtered in order to reduce the noise and the number of points. The stage allows merging multiple scan data sets, which is useful for large or complicated parts scanned in different positions.
- Generation of CAD model from RE data: polygonal models, surface models or solid models.

A very important issue to consider in RE is to define and manipulate the surface details so that the generated shape to be accurately represented and easy to modify. In this context, Non Uniform Rational B-Spline – NURBS surfaces represent a modern solution, very used in the field due to their advantages:

- Flexible design to a wide range of shapes;
- Compact expressions which can be quickly evaluated and displayed;
- Easy to manipulate control vertices, the curvature and the smoothness of contours;
- Can be generated from little data;
- Used to represent exactly the conic curves, with the added advantage of local control;
- Easy and stable evaluators, breaking and joining, degree elevation, and affine invariance. These surfaces can be constructed based on the CAD entities from the curve phase or by using polygon meshes for surface fitting.

The main objective of the NURBS surface definition phase in RE is to prepare a patch structure of quadrangu-

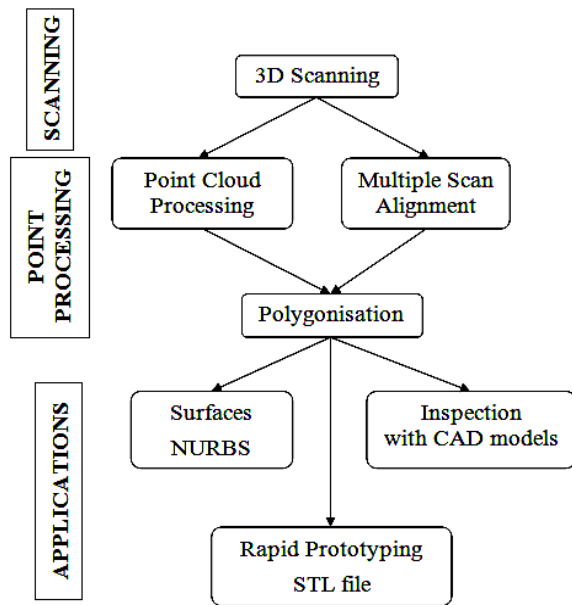


Fig. 1. General scheme for RE [5].

lar shapes for surface construction and for further utilization of the model. The patches can be drawn on the polygon model manually, semi-automatically, or automatically based on a target patch count and the curvature of the model.

3. RAPID PROTOTYPING PROCESS

RP technology is additive, the basic idea is that an object can be considered as formed by stacking very thin layers of material. Each layer is placed on the previous one and fused with it, in a position calculated by the system's software, and it is formed by photocurable resin solidification, filament material extrusion, ink-jet printing, laser fusion or lamination (SLA – stereolithography, SLS – Selective Laser Sintering, FDM – Fused Deposition Modeling, 3DPrinting – Three-Dimensional Printing, LOM – Laminated Object Manufacturing, etc).

The process chain starts with a digital representation of the object to be manufactured; this information is then converted in a neutral transfer format (STL format) and sent to the RP machine, which builds the physical prototype (Fig. 2).

In the early stages from the development of RP technology (1988 – first RP system, stereolithography – machine SLA150 from 3D Systems Co, USA), physical prototypes were built only starting from a 3D model obtained using a CAD system. Nowadays, the literature reports also other possible starting points for building a RP prototype: physical model: CT/MRI scanning data or CMM data; and computer model: 3D CAD data.

The availability of a physical object in the early stages of the development cycle can help avoiding the design mistakes, offers the possibility to evaluate different design variants, to obtain feedback from the clients, to start the parallel development of other aspects relating the product: presentations, brochures, packages. These have implications on the project costs and time.

Moreover, the continuous expanding of the material range (including metals, ceramics, elastomers, paper, etc.) and the improvements of the RP processes in terms

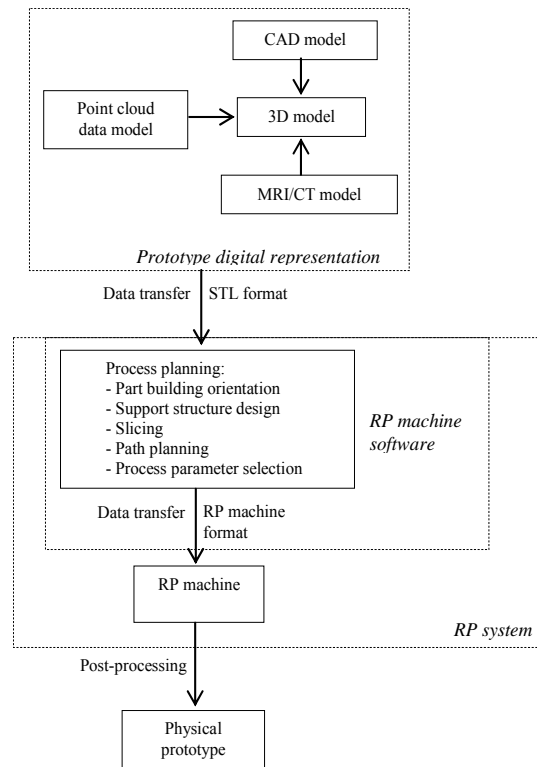


Fig. 2. RP process chain for building physical prototypes.

of accuracy, mechanical properties, surface quality, offer the possibility to build directly functional prototypes.

A drawback of RP processes is the staircase effect, inherent due to the additive manufacturing method. The staircase effect can be alleviated by using layers with smaller thickness (solution which increases the manufacturing time and costs), by using adaptive slicing or by an appropriate orientation of the part in the building process.

STL (the facto of the industry standard format for data transfer in RP) is a triangular representation of a 3D surface geometry. The surface is tessellated logically into a set of oriented triangles (facets), each one defined by the three vertices, in counterclockwise order, and the unit outward normal. The main advantage offered by this format is related to the fact that it is easy to generate from a large range of shapes representations, being based on robust and reliable algorithms.

However, due to their particular format, STL files have some disadvantages which must be corrected before sending the file to the RP machine. These drawbacks are: curved surfaces are approximated in terms of planar triangular facets (the deviation is controlled by the cusp height parameter), degenerated facets and incorrect orientation of normals.

4. RE AND RP INTEGRATION

A traditional product development cycle is presented in Fig. 3.

RE can be used in the initial phase of the product development process for providing a mathematical model of an existing part or sample.

In this case, the points cloud data obtained from a 3D digitizing systems are used as input in a 3D CAD software which performs the reconstruction of the surfaces and then of the solid part. The CAD model thus obtained

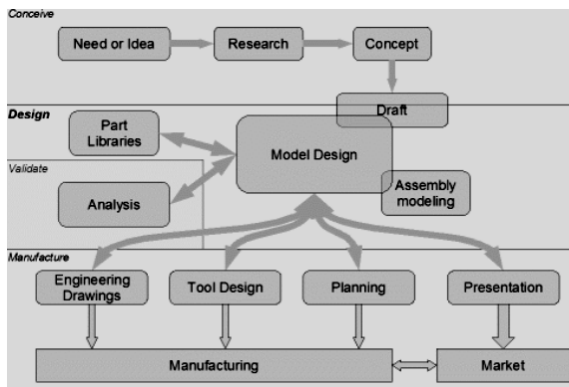


Fig. 3. Product development process.

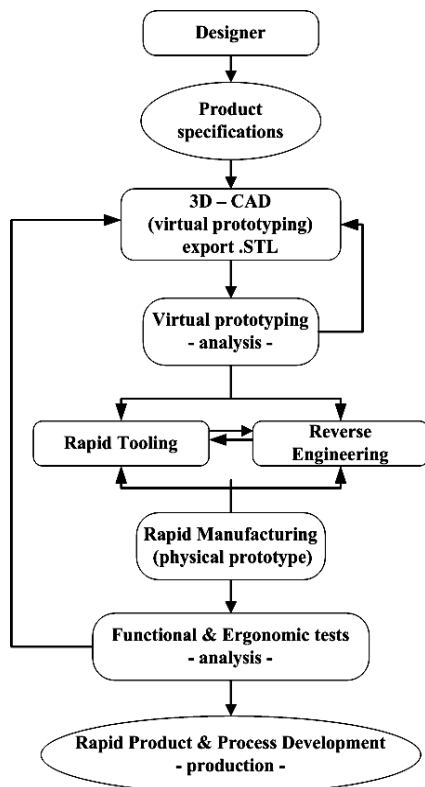


Fig. 4. Rapid product and process development approach [7].

is sent to the RP machine software in STL format. Figure 2 presents this approach in which the digital representation of an object can be generated from scanning data.

Another approach situates the RE process after the prototype is manufactured via a RP machine, as presented in [7] (Fig. 4). This approach integrates virtual prototyping for preliminary analysis, RP and Rapid Tooling (RT) technologies for building the functional prototypes and RE for metrology control.

As mentioned before, the CAD data is transferred in STL format which is sliced in thin layers and then sent to the RP machine. This workflow has the disadvantage that the RE modeling process and the RP slicing process are not integrated, causing shape errors for parts with complex geometries knowing that the layer thickness is maintained constant.

These errors are the sum of the error between the scanning data and the surface model, the error between the surface model and the STL and the error between STL mode and the layer-based RP model.

In [8] a new approach is presented, namely a method for slicing the point cloud directly in the building direction and generating a layered based model. This method eliminates the above-mentioned errors by applying an algorithm which converts directly the point cloud to a layer-based model for RP.

5. CASE STUDY

The application is organized following the integration procedure previously described. It starts with the point cloud model of a human face (in WRL format) which is imported in SolidWorks. The surfaces are reconstructed and the solid model and then the STL file are generated. The STL file is imported and checked for errors in Catalyst (FDM machine software) and different building orientations are analyzed in order to ensure the best quality of the surfaces.

5.1. Model, mesh recovering and cleanup

The WRL file of the scanned human face contains the coordinates of the measured points and viewpoint coordinates for the initial view of the model. The most important operations for optimizing the file are: to reduce the noise and to clean the gaps and the abnormal surfaces, to refine the polygon and mesh refinement.

A visual inspection of the model was performed before mesh preparation and cleanup. Figure 5 shows the WRL format, which was transformed into a polygon model. The holes were automatically detected and filled.

Considering that the model does not contain symmetrical features, and in order to reduce its dimensions and to speed up the surface generation, some simplifications were done, attempting not to influence too much the accuracy of the model.

Individual sub-meshes were identified by colors (Fig. 6). The sensitivity was adjusted to obtain a desired sub-mesh separation, which was improved in a later stage.

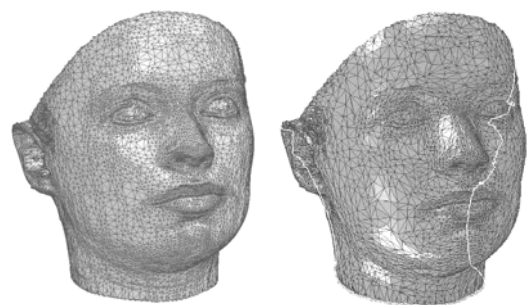


Fig. 5. Imported WRL format and polygon model.



Fig. 6. Individual sub-meshes identification.

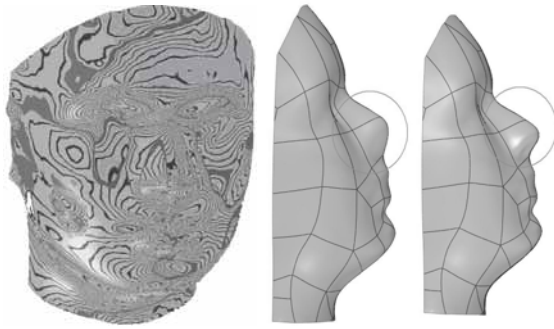


Fig. 7. Checking options and editing of the patches.

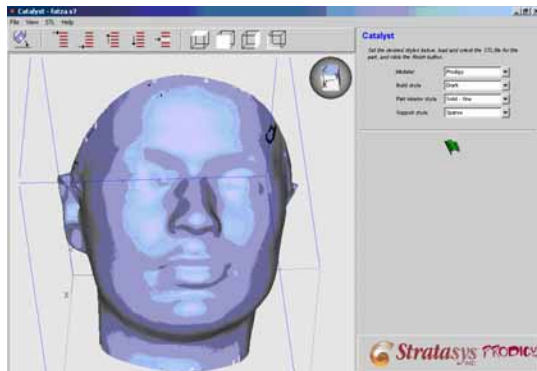


Fig. 8. Model processing.

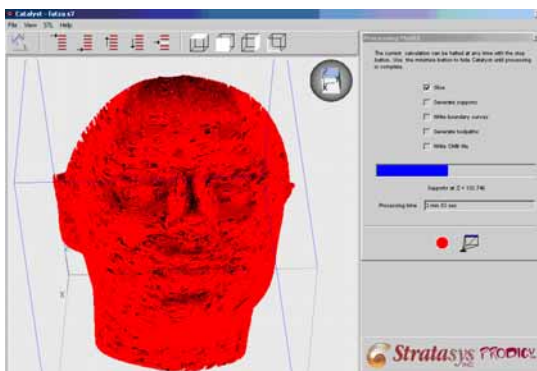


Fig. 9. Model processing.

5.2. Surface extraction and solid model generation

The NURBS patches were generated using guided creation of the faces in order to ensure better control of the shapes. Editing of the patches was needed because the nose of the model proved to be distorted, and new curves and control points were added on the NURBS surfaces for improving local details (Fig. 7).

The geometry and topology of the model were verified using "zebra stripes" option, in order to find the face imperfections, difficult to detect otherwise. Surface extraction converted all the regions into faces. When the base model was completed and the surfaces were turned into a solid, the model was saved in an STL format.

5.3. Model processing for RP manufacturing

In this stage of the process, the solid model of the human face was converted to STL file and imported in Catalyst software. Different building orientations were analyzed knowing that the quality is better when the sur-

face is oriented in vertical or horizontal planes. Moreover, for different orientation, the building time and the volume of support structures were calculated using the software (Figs. 8 and 9).

6. CONCLUSIONS

The paper is focused on describing a methodology for integrating RE and RP. The application of the methodology was made for the case of a scanned human face.

The advantages offered by this integration refer to a significant reduction of product development lead times. The main disadvantage is related to the cumulating errors from the surface fitting and triangulations.

Further research will try to find solutions to eliminate some of these errors and to improve the quality of the models.

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