A knowledge-based reverse engineering process for CAD models management

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Abstract: The paper presents a knowledge-based reverse engineering approach to identify several parametric CAD models from point clouds and manage the relationships between the CAD models. This knowledge intensive process enables designer interaction to capture design intents and to integrate digital data from previous product in a new product lifecycle. The obtained parametric CAD models are easy to change and to make evolve to design a new product using physical product data in a PLM approach. The paper presents the proposed knowledge-based reverse engineering process that implies to manage several CAD models generated from the same reverse engineering process. The data model used to link parametric features to point clouds, and to associate features to generate several CAD models that can be managed in a PDM system is presented. These CAD models can represent at least the physical product and the new one to be designed. It can also represent several views or product alternatives in the new design process.

Key words: engineering design, reverse engineering, reverse engineering process, CAD, PDM.

1- Introduction

Reverse Engineering (RE) is an activity which consists in digitizing a real part in order to create a numerical or virtual model. There are many domains related to reverse engineering such as, virtual prototyping where people compares a real model with the virtual model, metrology where people checks measurements, maintenance of long lifecycle product, tool design, art, entertainment, museology, protection of the industrial patrimony [LB1] and competitive analysis. This article proposes for mechanical engineering a new reverse engineering methodology where redesign purpose is needed. Redesign means that a product close to a previous one as to be designed for new requirements or manufacturing constraints.

For instance, a new design process is drawn to add new functionalities to an existing product. It can then be interesting to use the parametric CAD model of the previous product to modify the design parameters to re-enter the design process in the embodiment design phase.

In other word, the aim of a reverse engineering operation is to enable a redesign activity in order to improve the geometry of the considered part or to update this one.

Generally, the reverse engineering operation consists in converting a point cloud into an accurate model, minimizing the intervention of the user [BV1], [VF1]. Today, according to users, the results obtained using this classical approach are not good enough because the geometry obtained is generally "frozen" (i.e. a set of free form surfaces or a set of geometrical features in a manifold static model) and barely re-usable. To be re-usable and to enable redesign activity, a rebuilt model should be like a classical CAD model (i.e. a set of manufacturing and design features in a tree with constraints, parameters, rules and relationships).

The PHENIX project (Product History based reverse ENgineering: towards an Integrated eXpert approach) was created in order to suggest a software tool and to enable to obtain such CAD like model after a reverse engineering operation. This article proposes PHENIX approach which combines user interactions, geometrical recognition and knowledge approach. It consists in a combination between segmentation techniques, feature recognition techniques and user interactions using a knowledge based approach. The analysis of manufacturing processes and functional requirements represents a set of information which is implicitly integrated, as the designer intents, in a CAD model during a classical direct design process. In the reverse engineering context, this set of information, if explicitly integrated in the rebuilt model, allows the creation of design features as well as the relationships, the constraints, the parameters and the relationships between them.
The aim of the new approach presented in this paper is to produce and manage a set of "clever" CAD models in order to enable its reintroduction in a classical product development cycle (Figure 1). The paper doesn’t focus on the geometrical feature identification but on the way to produce a data model that enable to manage several generated parametric CAD models.

2- Reverse engineering and CAD models

The reverse engineering process begins with the digitizing of the product using technology such as laser measurement systems as illustrated in figure 1.

Then a specific software enables to clean the point cloud in order to keep only the part that has to be re-designed. Geometrical functions available in a specific reverse engineering software (such as Rapid Form or FocusRE) are used and enable to obtain a noisy point cloud. This point cloud represents the system to re-design. This point cloud can then be exported directly or using a tessellation step (eg in order to obtain a STL format file). From this geometrical data, a CAD software can then be used to view the tessellated surface obtained, as illustrated in figure 1. The main drawback is that this result is impossible to modify and to manipulate as a native parametric model. However, changes are most of the time useful. For instance, due to the measurement noise, the dimension between two holes should be re-adjusted. Entering a new design process, constraints such a geometrical tolerances should be specified and added to fit the constraints of the new manufacturing process. All these reasons lead to rebuild new CAD models (the original dead one, the original parametric one, the expected one...), using the initial digitized model.

3- Research objectives

In this framework, the aim of the PHENIX project (n°ANR-08-COSI-011) is to enable to build along the reverse engineering process parametric CAD models using a knowledge-based approach [F1]. Then a new reverse engineering process should be proposed to use knowledge as soon as possible in the reverse process to build not only one CAD parametric model but several ones, with respects to the assumption that are made along the reverse process [DR1][DR2].

During reverse process, assumptions are made about the reason for specific forms on the part due to the original functional specifications or due to the original manufacturing process for instance. These first assumptions drive to a first parametric CAD model namely the "as is" CAD model.

Another kind of assumptions concern the new design process (the reverse one) where the context has changed compared to the original one. The functional specification could have
evolved due to the knowledge acquired on the part usage. The number of parts to be built as well as the manufacturing means could have definitely changed compared to the initial part. Design choices have to be made according to this new design process, leading to design alternatives management. Then several parametric CAD models coexist (the "to be" models’ alternatives), and relations between these models have to be managed. For instance if a dimension is changed on a "to be model", it should impact the other “to be” alternatives but not of the "as is" model. The multi-representation problem imply to think about the way to manage the different models using a PDM (Product Data Management) system for two reasons:

- to structure and track the reverse engineering process;
- to manage the links between the different generated CAD models in order to manage engineering changes;

The research methodology is based on:

- a feature-based knowledge database to drive the reverse engineering process;
- a data model that supports to track the reverse engineering process and enables to manage multiple CAD representations.

The implementation of a new reverse engineering software tool is then proposed to validate our proposal and to test the proposal on several mechanical parts.

The paper first presents the model of a new knowledge-based reverse engineering design process. Afterwards, the data model needed to manage the association between the geometric features with the point clouds is proposed and the relation with the product data model that support the PDM integration is introduced. The aim of this integration is to enable the modification propagation in case of engineering changes.

### 4- Reverse engineering process model

The reverse engineering process proposed in this paper is built in order to integrate as soon as possible the specific knowledge that is used to design and manufacture a product to join the product life cycle as illustrated in figure 1. Therefore, mainly two steps of the RE process can be helped using a specific knowledge database. The figure 3 describes the whole RE process as proposed in the PHENIX project and underlines the two use of the knowledge base, for the segmentation and the feature association steps.

![Figure 3: The proposed knowledge-based reverse engineering process](image-url)

A formatted ASCII file (such as STL format) containing the point cloud(s) is the entry of the RE process. The first step of the RE process is the segmentation where algorithm(s) is (are) chosen to identify several groups of points in the cloud that belongs to the same geometrical entities. Algorithms are most of the time based on geometrical criteria, but algorithm using predefined geometrical feature can also be used. Especially, to avoid multiple RE operations on the same kind of part, the final parametric models obtained after the RE process can be stored as classes in a knowledge base. These classes can then be instantiated in order to be used as predefined features. These features are defined by the designer as basic feature or more complex geometry and are an interesting source of data for the segmentation process.

In particular, the generic problem of associating prior knowledge to geometric models has been widely studied by the Aim@Shape project (http://www.aimatshape.net). More in detail, there are results about:

1. the association of knowledge to geometric features in CAD models for an eventual redesign;
2. the extraction of geometric features based on prior knowledge;
3. the creation of knowledge bases describing geometric shapes partwise.

Today the above problems are widely described in the literature, and in particular in the area of CAD and reverse engineering. Segmentation techniques and especially skeleton based and clustering methods [A1] enable to identify point clouds in relation with a parametric geometry or a basic geometric entity. Most of the time, the geometry on the point groups from the segmentation step is used to identify a surface. Less frequently, a parametric geometry is identified in order to minimize the distance between a geometrical feature and the points of the point group. Limits are given in terms of error as the remaining difference existing between the identified feature and the initial points. In our case, the fact the geometry does not fit perfectly the points is not the
most important issue. Indeed, the parametric modelling enables to change the identified parameters to fit the new design need and constraints [AR2], [C1], [C2]. The potential of this approach is well demonstrated in [LV1].

In our case, the skeleton – skin model [SR1] can be used to have a generic representation of the features. It allows representing most of the generic mechanical features and the key characteristics of the model can be used to detect interesting geometry properties during the segmentation. At the end of the segmentation step, point groups are available for feature association. During the second step, geometrical features are associated to one or several point groups. A feature (defined as a class) of the knowledge base is selected and specific elements of the point groups are provided to help in positioning the feature in the point cloud. The dimensions of the feature are identified using interpolation algorithms such as gauss for instance. This step should be as automatic as possible, but most of the time it requires data from the user to have a better adequation of the result with the user intent. It should be noticed that the knowledge base can be structured using different criteria that are defined by the user. An ontology can be used to manage labels on the stored model to provide the multi-views representations.

As shown in this section, research works are leaded to support a knowledge-based reverse engineering process. However, they all focus on a lonely geometrical model of the product as output of the process. In this paper, we propose to add some concepts to be able to manage multi-CAD representation during the reverse engineering process.

**5- Data models to manage several CAD Models**

To be able to manage the multi-CAD representation during the RE process, an association must be kept between the points of the point cloud and the parametric geometry generated. The data structure that enables to manage this association is described in figure 4.

To explain this figure, it should be readen from the right to the left. The RE project contains several point clouds (if the product has been digitalized in several point clouds). On each point clouds, several segmentation can be done, using different algorithms or different set of parameters for the same algorithm, and point groups are generated from an initial point cloud.

Features are selected in the knowledge base and associated to specific group point(s). One parametric feature can be associated to one or more group points such as illustrated in figure 5. For the counterbored hole, two point groups have been identified during the segmentation step (the head screw one and the body screw one). Each of them can be associated to two different features (two holes for instance) or to one single feature (the counterbored hole feature), depending on the design intent.

From the feature definition and identification, alternatives are built using the following rules: alternatives are generated when more than one feature is associated to one point group. If two features are associated to one point group, then two alternatives are considered. When just one feature is associated to a point group, this feature is proposed in each alternative. Based on these rules, two alternatives are generated on the example of the counterbored hole in figure 5.

![Figure 4: The data structure to manage the relation between the product geometric models and the initial point clouds of RE project in a PDM system](image-url)
All the alternatives describe the same product in order to be managed in a PDM system.

![Figure 5: Example of alternative feature associations](image)

The illustration of the interest of the data model will be presented on an industrial example in the presentation of the paper.

## 6- Conclusion

The PHENIX project provides a framework to improve the RE process in order to integrate it in the product life cycle and to enable new product design development. The paper has presented the scientific challenges to address to provide models from the RE process as they would be if designed from scratch. Parametric CAD models and PDM data are provided during the RE process using a knowledge base approach. Further works will be done in two directions. First the management of the relations between geometric feature dimensions and constraints between features has to be included in the RE process. Second, the structuring of the database has to be defined and in particular the ontology that enable to manage the labels associated to the geometric feature classes.

The skeleton-skin approach has been chosen to model the geometrical feature in the knowledge base. The concepts are implemented in the PHENIX application that can provide a stand-alone version and generate XML files structured as defined in the Core Product Model [SF1], and where the information of the associations with the point groups and point clouds of the RE project are added. Another version is implemented, integrated in CATIA V5 CAD software, and using User Defined Features (UDF) to implement the knowledge based approach.

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## 7- References


