ADVANCED PROTOTYPING WITH PARAMETRIC PROTOTYPES

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The "Parametric Prototype" has been developed as a tool for integrated parametric and physical shape representation to optimize styling and design. This tool will be applied in the early phases of the product development process at an appropriate level of detail, e.g. for the fast visualization of car parameters and proportions of the exterior car body. The development comprises a method that converses changes in the product model in a CAD system and the physical model bidirectional. Further the implementation of an interface between the physical shape presentation and the computer based representation has been realized.

1. INTRODUCTION

The competition on the automotive market has increased during the last decades. This can be explained by changes in the behavior of the class of consumers and the positioning of the automotive manufactures (Grabowski, 2002). Connected with this are saturated markets, especially in the automotive section (Kurek, 2004). The manufacturers have to adjust rapidly to changes in the demands of customers (Wagner, 2004). This results in a flood of new concepts and product variants on the manufacturer side (Ebel, 2004).

The applied process in the early phases of the product development process between styling and design is characterized by numerous virtual and physical models of the product. One possibility to create physical models from virtual models is Rapid Prototyping (Gebhardt, 2000). The reverse process, to create virtual models of real objects, can be performed by applying 3D scanning techniques. These transitions between physical and virtual reality, lead to so called media breaks. A possible consequence is the loss of data and data quality in the process.

This paper comes up with a solution how the physical process can be connected to the virtual process by an integrating application. Media breaks are avoided. Based on the methods of product data management, a form for the physical representation is developed at an appropriate level of detail. The parametric support of the process leads to a reduced number of iterations in the product development process. The term 'parametric' is extended in this case to the variance of physical objects, which size and shape are connected to parametric values, not only the virtual representation.

2. PRODUCT DEVELOPMENT AND STYLING

In the early phases of product development the styling of the product is dominant. This is especially true in the automotive industry where styling is essential for the success of a product. The styling of the automotive body shell is inevitable time consuming. Depending on the draft of the exterior styling, the tool design builds the forming tools, which is a time critical factor in the product creation process (Anderl, 2005).

The aim of the styling process is the development of several competing drafts, to scale presentation models. The presentation to the deciding committee leads to the final decisions over the final vehicle (Mischok, 1992).

The product development process with special consideration of the design demands for the following requirements, to reduce development time and costs while increasing the quality of the product:

- An efficient integration of computer based methods in the process.
- The creation of several design variants.
- The prevention of media breaks.

Contemporary traditional techniques dominate the state-of-the-art styling process. These techniques are characterized by artistic and technical skills (Spur, 1997). Despite a high number of iterations, there is no parametric tool, which can support a consistent presentation of the constantly changing models appropriately.

3. VIRTUAL AND PHYSICAL PRESENTATION

The term “model” is understood within the range of engineers according to VDI (German Association of Engineers) as an abstract representation of a product (e.g. by its data, characteristics or shape). The abstract representation of a product can be thereby both digital and physical. The expression “prototype” is also used for physical and digital representations of the product.

Physical models and prototypes

A physical model is an object or set of objects that is generated from a variety of materials to approximate an aspect of how a product concept will look like and perform. Synonymously, the term physical prototype is used. It is tested under a certain range of conditions to approximate the performance, constructed to control possible variety in the tests and it is used to communicate empirical data about the product so that development decisions can be made with high confidence and reduce risk (Otto, 2001).

Physical models and prototypes can be distinguished into six major classes, which are the proportion model, the ergonomics model, the design model, the functional model, the prototype and the product sample.

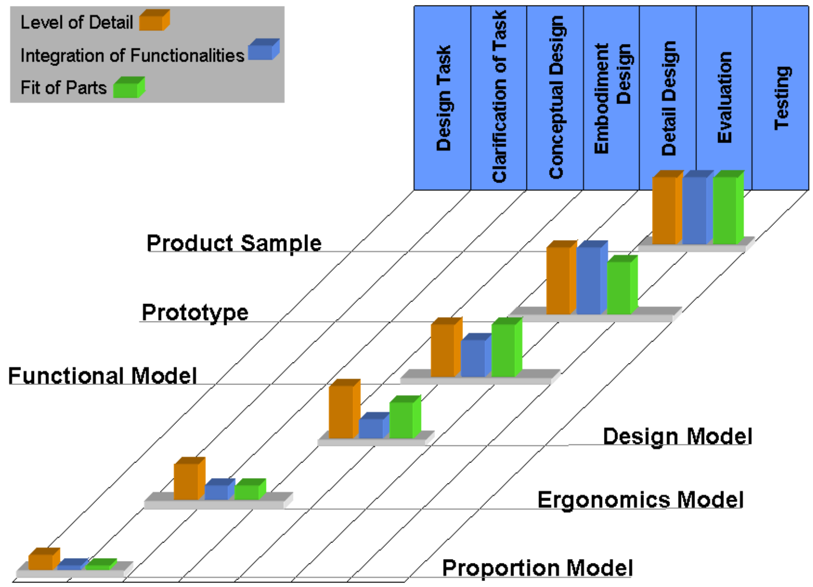

Figure 1: Use of physical models in the product development process.

Figure 1 shows the allocation of physical models according to the product development phases, based on the VDI 2221 guideline (VDI, 1993) with the qualitative rating of the level of detail (left bar), the integration of functionalities (middle bar) and the fit of parts (Klug, 2004). Proportion models show the approximated outer shape of the product and its most important proportions. Numerous proportion models are generated during product creation, which leads to delays in the process.

Virtual Prototyping

Virtual prototyping refers to build a complete prototype assembly with geometric models of individual parts. Virtual prototyping systems allow the visualization of part assemblies and the feasibility check of proposed assemblies within production constraints. Through the assembly of an accurate virtual prototype, design flaws can be detected and design modifications performed (Lee, 1999). The virtual engineering process starts from geometric 3D-models, proceeds to the simulation of production systems and finally reaches the building of a digital mock-up, digital prototype or digital product (Klug, 2006).

All available physical and virtual models, methods and tools can not avoid a media break in the iterative product development process as a whole. From the requirement to make a physical model available for fast visualization of fundamental design characteristics, e.g. approximated proportions of vehicle, the parametric prototype has been developed at the Department of Computer Integrated Design (DiK).

The process of proportion definition can be defined on the basis of its input and output data. The input is the package data. The output is the freezed concept model. The package is defined as the process of transforming geometric and technical requirements, given by technical or ergonomic defaults and laws, and the styling theme, for example racy and classical. Aesthetical modifications can be done within the given set of styling tolerance; the minimum and maximum value of a package parameter.

Tools usually used for this process are full-scale sketches and sketch-models. At this point, the process can be supported by the parametric prototype, consisting of the parametric model and parametric mock-up. Figure 2 shows the generalized aesthetic design process referring to the FIORES report (FIORES I, 2001; FIORES II 2002) extended with the application of a parametric model and mock-up.

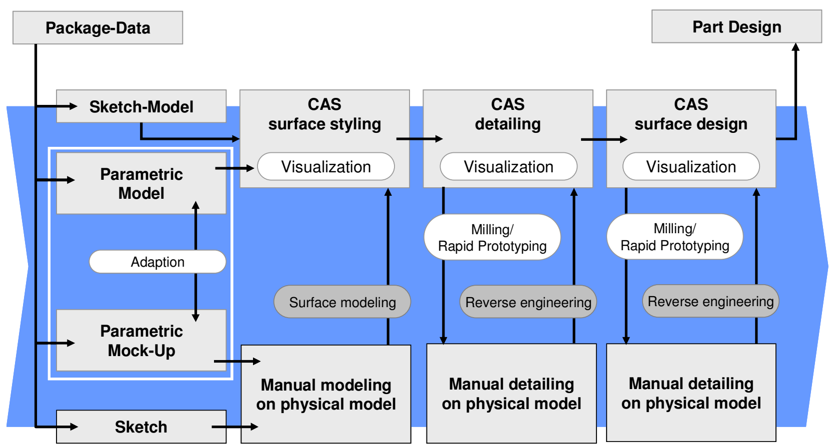

Figure 2: General process chain with parametric model and mock-up in styling

The parametric prototype can be defined as the set of a physical mock-up and a virtual model which are linked by an interface. Thus the parametric mock-up is a physical model which is used in the concept phases of the product development process for preliminary styling purposes. The outer shape of the parametric mock-up can be modified in a preset range by mechanical, electrical and control components in context to the parametric model.

4. THE PARAMETRIC PROTOTYPE

The concept consists of the virtual parametric prototype and the physical mock-up, which are connected via a hardware interface and software.

Conception of the virtual parametric prototype by segmentation

Based on the chosen parameters for variation of the car geometry, for example the total length, width, height or length font, rear, a concept for the segmentation of the car geometry is developed in this chapter by applying a number of half spaces. The complete object space is split into several primitive volumes, which are represented by simple sets. By applying these half spaces the orientation of planes can be considered (Spur, 1997).

The half spaces, with the definition of the inside, are representing the boundaries of the description of the volume element. For the generation of a fully described, topological-geometrical body, the surface description of the vehicle can be used. This can be done by using trimming and blending operations, applied on the planes and surfaces. Finally, the vehicle volume is described by several bodies, which are generated from spaces with multiple boundary planes.

In order to change the shape of the vehicle presentation by using the parametric prototype, several constrains have to be defined. These constrains are deduced by analyzing the directions of movement to change a specific measure. Based on this analysis, the partial volumes of the parametric prototype are combined to movement groups.

The parametric mock-up

Referring to the definition of a parametric Prototype, the mock-up serves as a physical presentation form. It can be changed in shape within a specific range by electrical, mechanical and control components. The parametric prototype is connected by a hardware interface, which passes the input signal on to the control components. Linear actuators and the framework enable the generation of a movement of the volumes by transforming signal and electric energy and represent the mechanical components. Sensors return the position of the volume elements to the control components. The output is the visual impression generated by the variation in form. A ‘zero position’ or undeformed neutral position is given by limiting switches of the linear guides.

Interface

To generate the control data, multiple steps have to be performed. The bases of these calculations are the different volume elements, defined by half spaces like described above. From the set union of half spaces and surface description, surface patches can be derived. These patches are used for the calculation of data of the displacement in one specific direction. To save the model specific segmentation, a special file format, base on the STL- file format, has been developed. Starting from these geometrical descriptions, the steps, input data, ‘fitting’, ‘matching’ and output of the control data are performed.

In the first step, the design data, that is supposed to be presented by the parametric prototype, has to be loaded into the system. The process ‘fitting’ is used to fit the geometric data into the space that the physical parametric mock-up can be adjusted to. For this procedure, translation, rotation and scaling transformations are applied. In the case that the design model contains a coordinate system according to the convention specified in DIN 70020, the fitting process is not needed.

The next step for the generation of the control data is the matching process. The surface patches from the segmentation process are fitted to the geometric data. The displacement gives the end position of the actuators. The process has to be performed for every patch representing a volume element of the physical parametric prototype. The control data is derived from the displacement information with additional information about the actuators, represented by the constraints. A graphical display of the overlapping surfaces is used as control output. The degrees of freedom of the actuators moving the surface of the physical parametric prototype are the parameters to be varied, while the geometry of the surface, represented by curvature and dimension are not to be changed. A mathematical criterion for the determination of the distance between the two surfaces has to be found. Several criteria are possible, e.g. the mean error minimization, squared error minimization, the Hausdorff distance or a Salient Feature Matching. The decision, which method suits the purpose best has to be made by the observer of the result.

The calculated data from the matching process represents the displacement of the volume elements. The control data is calculated form this data with additional information of the physical parametric prototype.

Depending on the situation it is necessary to move two actuators at the same time. Therefore two positioning procedures are needed. One realizes the movement of an individual block and one for the realization of a combined movement of two blocks.

Specific control libraries using USB are the interface between the control unit hardware and the personal computer. These libraries are loaded and called form the Software, which is performing and direction the calculations and the output of the data. The control unit provides the necessary electrical power to the actuators ant the status of the switches is monitored constantly and handed back to the controlling software.

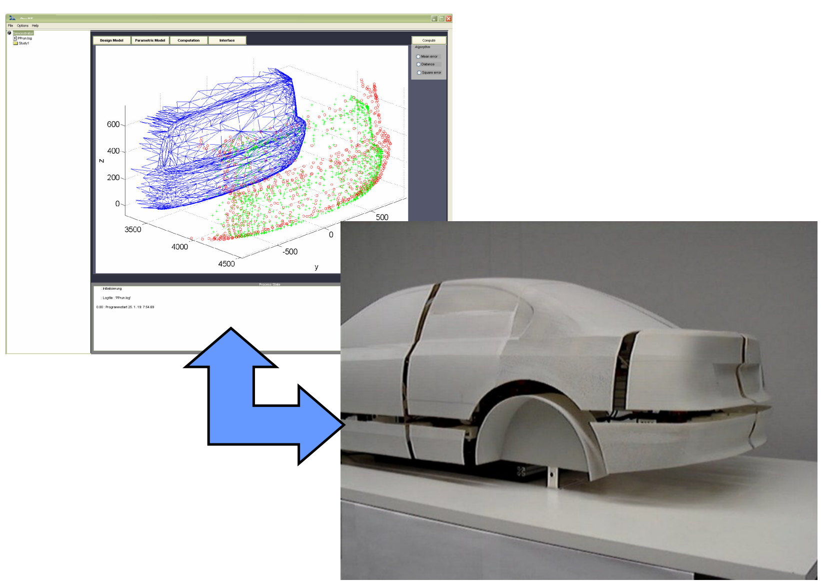

Figure 3: Interaction of Graphical User Interface and physical parametric prototype.

The parametric prototype in action

Figure 3 shows the GUI and the physical parametric prototype. An export of native CAD or DMU data in a standardized geometric data format or starts the calculation software. Automatically, an additional user dialog is started. The user has to confirm the data. By doing so the described calculation steps are performed. In case the data set can not, or only poorly, be displayed the system outputs a warning message.

After that, the control data is calculated and send to the physical parametric prototype, which adjusts to the given geometrical representation, with the mechanical degrees of freedom as limiting factor. The control data can be distributed to several physical prototypes for collaboration to support video conferences.

5. CONCLUSIONS

Beside technical features, the styling of a product is very important for branding, and product differentiation, which are crucial criteria for the success of a product. This applies for the automotive industry in specific. The styling process in the early phases is characterized by generation of numerous models in virtual and physical reality. Transitions between physical and virtual reality world lead to media breaks. The claim for the application of virtual tools only is an approach to avoid these breaks, but an analysis of the state-of-the-art technology has shown that there are still immense deficits. The reason for that can be found in the insufficient development of styling tools. Designers are not supported to a desirable extent in their function, which leads to a rejection of these virtual tools and methods. Another reason is that the human perception of objects prefers physical objects, because of natural sensation. Therefore physical presentations are given a higher priority by the designer. Further, the support of parametrical tools is missing.

Based on the foundations of product data technology, an analysis has been performed on the existing tools and methods. Virtual and physical tools have been compared and differences, as well as possible interfaces have been shown. One possibility to generate a physical presentation form of virtual models is Rapid Prototyping. An inverse process, the generation of a virtual model from physical shapes, can be performed by 3D-scanning. The developed concept introduces a new method and a new tool for a parametric support of the product development process. The method is based on a system of planes which define several half spaces. A number of constraint and parametric volume elements are defined this way.

The concept is put into practice by the construction of a physical parametric prototype and the implementation of a software interface. With these demonstration tools the analysis of proportions in the early phases of the product development process is possible. Integration in existing CAD- and CAS- systems, as well as information model in existing product data management systems is possible.

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Reiner Anderl studied mechanical engineering at the University of Karlsruhe where he reached his diploma in 1979. He worked as a research assistent from 1979

until 1984 at the Institut für Rechneranwendung in Planung und Konstruktion (RPK) of the University of Karlsruhe and received his doctor degree in 1984. From 1984 he took the position as technical manager of a medium sized company. Since 1985 he was working as chief engineer at RPK. In 1991 he achieved his habilitation and in 1992 the venia legendi which includes the authorization to teach CAD/CAM technology. In April 1993 he received the professorship for computer integrated design at the Darmstadt University of Technology.

Prof. Anderl participates in the ESPRIT project 9049 PDTAG-AM (Product Data Technology Advisory Group - Accompanying Measure) and chairs a research group on product model development in the German QCIM project (Quality Management based on CIM). The ProSTEP association he has been elected as scientific advisor of the management board.

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