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INTEGRATING REAL GEOMETRY MODELS INTO PRODUCT SIMULATIONS: AN APPROACH OF A KNOWLEDGE-BASED PROCESS

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1. Introduction and motivation

Simulation driven product development is state of the art to predict that the desired characteristics in use behave as requested before performing lots of time-consuming tests using expensive prototypes. To achieve the aim of precise, realistic and reliable results within these product simulations, enormous expense is spent. Therefore various non-linearities, like material behaviour, contact situations, large deflections or changes of boundary conditions, are taken into account. Contrary to the consideration of all of those complex non-linearities, still the ideal geometry is always used for the analysis [Gebhardt 2011], despite knowing the effect, that every manufactured component shows differences to its ideal CAD-model (Figure 1). Besides random deviations, these differences can vary depending on among others the manufacturing process [Söderberg 1998] and the component size. In cutting processes the size of deviations is relatively small, but using other manufacturing techniques, process-related effects may occur and can trigger bigger deformations. So, spring back [Bartenschlager et al. 2013] and drapery [Birkert et al. 2013] may arise when using forming techniques (i.e. deep-drawing or bending) or when using various casting processes (i.e. die casting or injection moulding), effects like shrinkage [Nee 2014] and warpage arise. These effects can also cause large deviations and are a result of the solidification and cooling of the component in the die, due to separating sprue and overflow system or due to inhomogeneous temperature fields when cooling to room temperature at components with differences in wall thickness [Thoma et al. 2013].
It seems rather doubtful that further refinement of simulation methods makes sense, when the actual manufactured geometry of the component is not considered for the simulation (Figure 1). Here a knowledge-based process is presented to decide up to a certain point the ideal (CAD-designed) model can be used or when and how a model should be prepared with real geometry information (deviation afflicted shape after the manufacturing process).

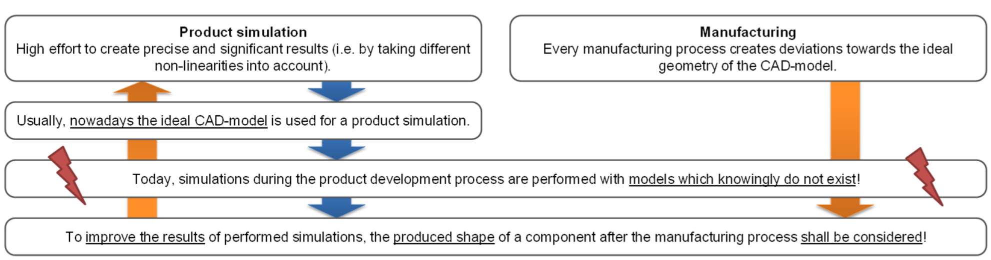

Figure 1. Background and motivation to use real geometry data for product simulations

Due to the described issue an approach of a knowledge-based process is outlined and verified with a consistent example in the following.

2. Desired process for the integration of real geometry models

As mentioned above, the real geometry of the component should be considered when performing simulations (i.e. structural mechanical analysis) in order to get results close to reality. For this purpose, the following process (Figure 2) is developed to support engineers to make a decision, whether appearing deviations are critically or not referring to the performed analysis. Therefore, a knowledge-base is deposited within this process to give all relevant information about the product, the required analysis and the manufacturing process as well as facts about the used metrology systems. Furthermore, if real geometry data should be used for simulations, depending on the progress of the development, different methods to prepare the model are proposed (i.e. if there is an FE-model already available you could use an algorithm to adapt the FE-mesh to the digitalised geometry data and need no further pre-processing, refer with chapter 5).

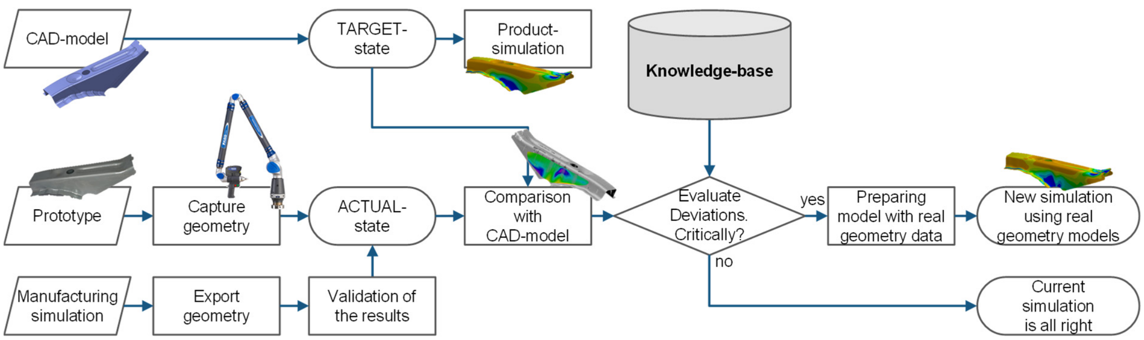

Figure 2. Desired process for the integration of real geometry data into product simulations

Besides the presented process, CAT (computer aided tolerancing) methods to create geometric deviations of manufactured parts and to perform statisitcal variation ananlysis are used, like regression analysis [Schleich and Wartzack 2012] or Monte Carlo simulations [Grossmann 1976] (for example within the software for Robust Design and Tolerance Analysis [RD&T 2016] by Rikard Söderberg). Herein a large amount of variatons of assigned tolerances are calculated in order to get a probability of the deviations. These simulations are very specific to one single manufacturing process and the according production machines and furthermore, complex daviations may not be detected. So the presented approach is not to replace known and aprooved CAT methods. This furthermore should complement known methods when off-tool prototyped geometry or a reliable product simulation is available for analysis.

3. Generation of a real geometry data set (ACTUAL-state)

To get the opportunity to prepare the model with real geometry data there are primarily two ways to create those information - the detection of a real prototype or a simulation of the manufacturing process. In the following, both methods are explained closer and the main advantages and disadvantages are pointed out. In any case, afterwards the CAD-model (TARGET-state) can be compared to the ACTUAL-state to identify the differences between the ideal and the real model.

3.1 Creating ACTUAL-state data by capturing geometry using 3D surface detection

An easy way to generate real geometry data is by digitalising an off-tool prototype. Therefore, optical 3D surface detection devices are basically used, since they are fast, stable, relatively cheap and have a reasonable accuracy of around ±25µm [FARO 2015] and even more precise.
Based on the principle of triangulation, two commercially methods for digitizing are available - the laser light section method and the structured light method (Figure 3).

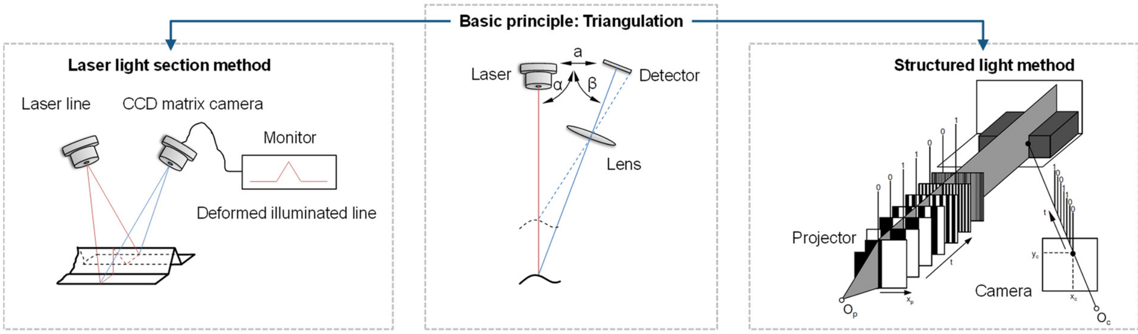

Figure 3. Functionality of triangulation and usage as laser light section method [Katona et al. 2014b] and structured light method [Gühring 2002]

With the laser light section method a laser line illuminates the object and a camera with defined distance and angle records the deformed line (Figure 3 left). Having a relative motion between scanning system and object, in predefined distances lots of lines are detected by the camera to capture the surface of the object.

The structured light method is basically the same except several parallel lines of light-dark transitions are projected on a large area of an object at once and a matrix camera detects the deformed lines. To ensure a clear allocation of the individual light-dark transitions a coding must be used - usually a time encoded binary pattern (Figure 3 right).

Both methods create either a point cloud or a polygonal model of the object. The points only consist of three xyz-coordinates and do not bear any relation to each other. A polygonal model is created with suitable algorithms - like Delauny-algorithm [Delauny 1934], [Ottmann and Widmayer 2012] - from the point cloud. Both data types can be used for comparison with CAD models and are the bases for a surface reconstruction, but cannot be used directly for generation of geometry within CAD systems.

3.2 Creating ACTUAL-state data using simulation

In addition to the 3D surface detection, it is a concern to substitute the three-dimensional surface scan of the real component with a simulated manufacturing model for this purpose (for example using software by AutoForm© for sheet metal parts or Moldflow® by Autodesk® for injection moulding parts). Consequently, the engineer has the opportunity to analyse the component with real geometry data in an early phase of the product development process [VDI 1993], even before there is a deformed component as a prototype at hand. Within the context of a "digital mock-up" [Scholz et al. 2006], the renunciation of the real manufactured prototype has to be aspired, but still those manufacturing simulations do not have a sufficient precision compared to a real component, making a prototype currently still irreplaceable.

4. Knowledge-base and flow of knowledge

The knowledge-base (Figure 2) itself consists of two main blocks (Figure 4). On the one hand side the product-specific knowledge which contains all information about a single part. Meaning the dimensional and geometric tolerances are deposited in here as well as the desired function of the component and the integration within the assembly. Furthermore, the results of comparison of TARGET- and ACTUAL-state and limits / permissible deviations of the geometric differences are stored in this block. On the other hand, the process-specific / general knowledge is deposited to give information about the manufacturing process with its concrete possible deviations (i.e. drapery when using the technique of deep-drawing) and the general tolerances of the process. Additionally, information about different systems for the digitalisation of prototypes can be figured out, with the explicit accuracy of every systems and if necessary of the data preparation. Between both blocks the analysis knowledge is located, since this is part of process-specific knowledge when performing manufacturing simulations but also product-specific knowledge with the results of product simulations, the flow of force through a component and comparative analysis of previous versions or similar parts.

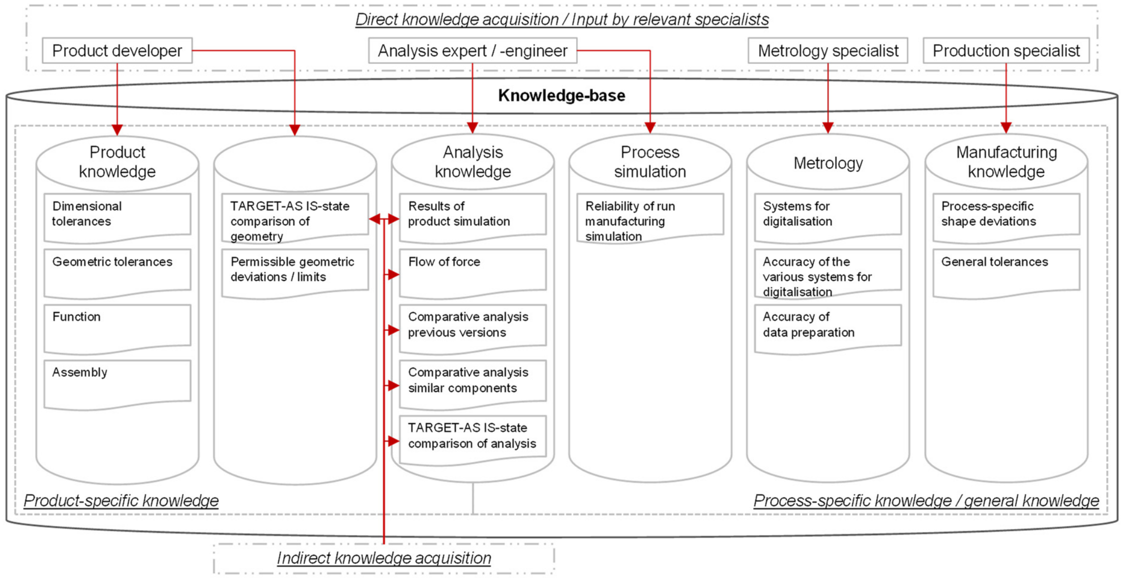

Figure 4. Structure of the knowledge-base and flow of knowledge

To fill the database with knowledge methods of direct (input by experts) and indirect (flow back from the process) acquisition are applied.

The basic knowledge is entered by the relevant specialists for each topic. For the product, the responsible product developer characterises the dimensions, the function of the product and the position in the assemly as well as the permissible geometric deviations of the manufactured part to its ideal. The manufacturing knowledge is given by a production specialist who has a concrete idea of the occurrence of process specific deviations. Data about the use and accuracy of systems for digitalisation are provided by the metrology specialists. And finally, the analysis expert / simulation engineer stores the results of product simulations and information about the manufacturing simulation where appropriate.

Besides the direct knowledge acquisition, it is the aim, that the results of the presented process flow back into the knowledge base. Thereby, information about the comparison of the geometry, the analysis or analysis of similar components can create new knowledge to support the product developer finding permissible deviations for the parts for this and future product developments.

Based on the accumulated knowledge, a decision about the significance of performed analysis concerning the geometry can be made. For example, with flow of force within large deviated areas, a preparation of the model with real geometry data should be aspired.

5. Methods to prepare the simulation model with real geometry

When the evaluation of the occurring deviations shows that the differences of the real model compared to the CAD-model are relevant for performing simulations, the knowledge-based process provides various methods to prepare the ideal simulation / CAD-model with real geometry data (Figure 5).

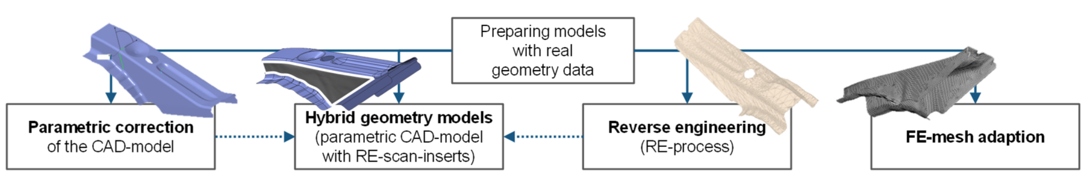

Figure 5. Provided methods to prepare the model with real geometry data

5.1 Parametric correction of the CAD-model

Whenever possible, the parametric of a CAD-model should be maintained to keep the product model consistent through the product development process. To achieve this, the first suggested method to prepare the model is to create a new deviated CAD-model by modifing the parameters of the design

CAD-model. Therefore, regular geometry elements (i.e. plains, cylinders or cones) could be extracted from the model and the ACTUAL-state of those elements can be measured. The value of the measurement is returned to the CAD system and the real shape can be created.
The main disadvantage of this method is that only simple manufactuting deviations, like the wrong angle at a bending process through spring back, can be corrected. Complex deviations, for example drapery from deep-drawing manufacturing, would be very hard to reproduce with design features within a CAD system. Besides this, a parametric model is not always at hand. In most cases for a supplier just data, which meet the requirements for neutral data formats [Troll 2014], like STEP [ISO 10303] or IGES [US PRO 1996], are available, since almost every OEM wish to disclose any company knowledge of the product. Therein are the limitations of this method.

5.2 Reverse engineering (RE-Process)

Reverse engineering (RE) describes the procedure of returning a real existing component into a CAD-model [Percoco 2014], [VDI 2015]. The process of RE is a generic process [Raja and Fernandes 2008] and essentially includes three steps (refere with Figure 6) [Katona et al. 2014b].

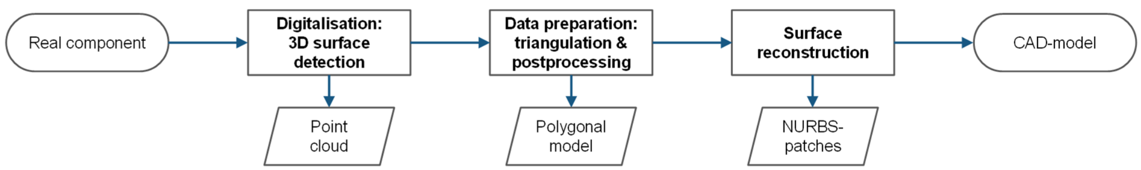

Figure 6. The reverse engineering process

The RE-process starts with the steps of digitalisation component to a point cloud and the triangulation to polygonal model described before. Furthermore, within the second step a post-processing of the scan data is frequently required (this implies smoothening surfaces, closing holes from undetectable areas or manual deleting of wrongly captured areas through noise or mounting brackets). The third and last step comprises the reconstruction into a CAD surface model. Therefore, the polygonal model has to be segmented into four-sided areas. Each area will be described as one surface patch later. A standard for a mathematical surface description is by using NURBS surfaces. These surface patches offer an exact description for both, analytical standard forms and free-form surfaces. Other advantages of NURBS-patches are: a relatively small memory usage, because only control points, grid and knot vectors have to be saved, as well as the speed and numerical stability of NURBS-algorithms [Piegel and Tiller 1997]. The surface reconstruction, in general, is a very complex and time-consuming part of the RE process. Approximately 80% or even more of the total time in reverse engineering is often used for segmenting and reconstructing the polygonal model to surfaces [Schöne 2009].

5.3 Hybrid geometry models

To combine the advantages of both previous mentioned methods, on the one hand the use of parametric CAD models and on the other hand the general validity, general usability and flexibility of a surface reconstruction, an approach to create hybrid geometry models for simulations was made [Katona et al. 2015a]. These hybrid models result from the parametric CAD-models for the most areas of the part, but areas with large or complex deviations are substituted by scan-inserts (Figure 7). Those inserts consist of surface reconstructed NURBS-patches based on the recorded data set of a real components 3D surface scan. Using this procedure, the amount of data - compared to the scan model - and the time for model preparation (mainly the surface reconstruction parts) can be reduced to a minimum.

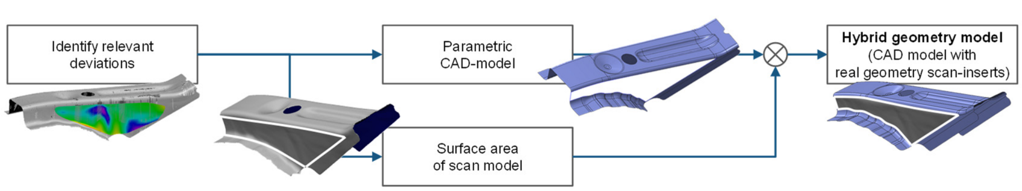

Figure 7. Strategy of creating hybrid geometry models

5.4 FE-mesh adaption

The approach of an adaption of FE (finite element) mesh is an opportunity to use existing FEA (finite element analysis) simulations, based on the non-deformed CAD geometry [Katona et al. 2014a]. The advantage can be seen in the omission of a complex design of a new model for simulating the real geometry. Thus, this method is applied, when an FE simulation with ideal geometry is performed already.

Within this algorithm the deviations at the every surface node towards the scanned geometry data (either point cloud or polygonal model) is measured. Those deviations are applied as displacements using a preload step to the actual analysis [Katona et al. 2015b, 2015c]. The resulting mesh is finally used for the actual simulation with real geometry (Figure 8).

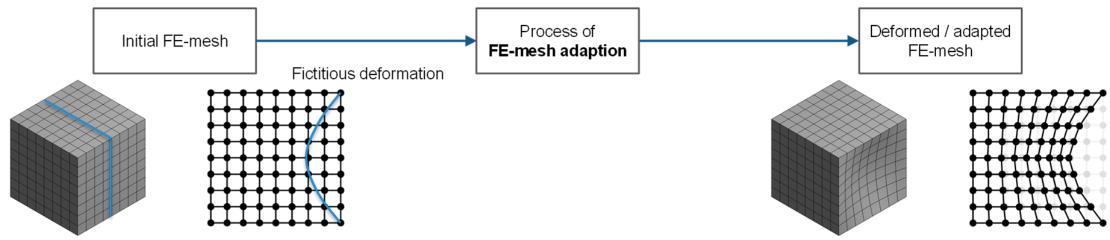

Figure 8. Exemplary presentation of the FE-mesh adaption method

6. Implementation as software demonstrator and future work

The main task for the future is the implementation of the described knowledge-based process to integrate real geometry models into simulations in a software demonstrator. Therefore, the idea is to use the ANSYS® Engineering Knowledge Manager (EKM), since it "[…]provides an open collaboration platform for simulation IP management" [ANSYS 2011], [Kestel et al. 2015b]. Within this software you can store the explicit knowledge and get access to the situational knowledge when needed. Additionally, the workflow can be created and managed with a graphical interface. Furthermore, it enables common visualisation for various CAD/CAE data types.

Figure 9 shows the partial implementation into the operational demonstrator using ANSYS EKM.

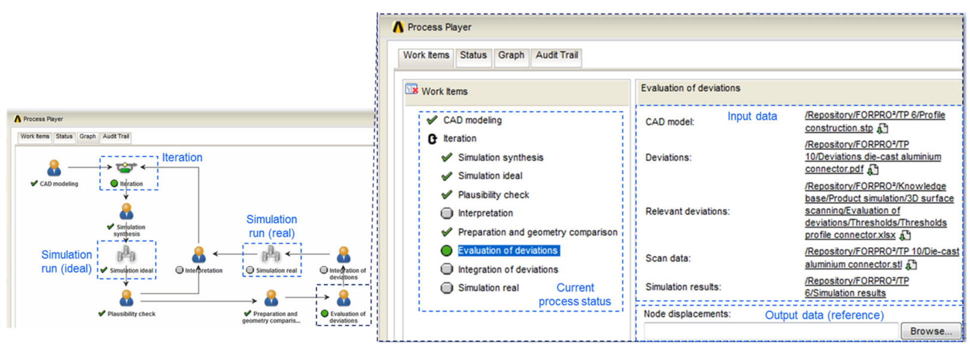

Figure 9. Mapped simulation processes and dialogue component to evaluate and integrate deviations [Kestel et al. 2015a]

Finally, the process shall be validated exemplarily within an industrial partner using the specific knowledge of the intern specialists with their belonging to the firm products, manufacturing techniques and processes.

7. Summary

To sum up, almost every produced component differs in its geometry compared to the ideal model of the CAD-system. Those deviations due to the production process can trigger various influences on the results of performed analysis. To identify and evaluate these differences of TARGET- and ACTUAL-state the presented knowledge-based process is developed. Within this process a knowledge-base supported decision can be made, whether performed simulations / analysis return applicable results or not. If it is suggested, to use real geometry data for the simulation due to relevant deviations of the manufactured component towards the ideal CAD-model, different ways of updating the model - depending on preliminary work - are provided.

Concluding it can be pointed out, that this process can help to increase the efficiency of the virtual product development through the use of real geometry data and the knowledge when and how to use it.

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