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Introducing Trimming and Function Ranking to SolidWorks based on Function Analysis

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Abstract

TRIZ based *Function Analysis* models existing products based on functional interactions between product parts. Such a function model description is *the* ideal starting point for product innovation. Design engineers can apply (TRIZ) methods such as trimming and function ranking to this function model to improve their products. This paper describes the introduction of said methods directly into CAD software, since this is software often used by design engineers. As such, design engineers do not have to switch between applications, or worse, convert product data sets, when jumping from product detailing to innovation tasks. The developed software tool tries to actively guide engineers through the innovation process, progressing more quickly through product design and redesign phases. Thus, resulting in shorter lead times and a faster time-to-market for the industry.

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Keywords: TRIZ, Function Analysis, Function Model, Trimming, CAD

1. Introduction

This paper describes the introduction of trimming and function ranking to SolidWorks based on TRIZ function analysis. Currently, the integration between Computer Aided Invention (CAI) and Computer Aided Design (CAD) software is very limited. This study aims to bridge this gap by developing software that establishes an integration between both activities (i.e. innovating and detailing). This allows users (design engineers) to progress more quickly through product design and redesign phases, resulting in shorter lead times and a faster time-to-market.

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Currently, there is a trend towards semantic processing of information to recognize or store relations between pieces of information and to give them a meaning. This is, for example, widely researched in natural language processing and in information searching. Also, the principle of tagging information on the internet has become very popular since the rise of social networks.

In this research project, information will be linked between CAD parts and *Function Model* components, between interactions and functions (in the CAD software and the *Function Model*, respectively) and between functions and phenomena. After providing software with rules for semantic processing, the software can establish links between the information and assist the user in using this [1].

In this introductory chapter, first the concept of (TRIZ) function analysis is described. Next, trimming and the effects thereof (change propagation) are discussed. This leads to the goal description of this research and outline of this paper.

1.1. Function Analysis

Mathematics, probably the most advanced modelling technique ever, has a great level of abstraction and formalism. Once we model, say, a manipulator by a system of differential equations, there are no more details such as drives, joints and bearings. What is left is basically a balance of functions these elements perform on each other. So, the design of a new system for a professional physicist begins with designing a new mathematical model that describes the manipulator. Having been satisfied by the theoretical design (functions the designer obtains from solving the mathematical model), the designer tries to come up with material objects that would perform the functions required by the model. Hence, going from the abstract level to concrete parts. Mechanical, hydraulic, pneumatic or magnetic forces (drives) may appear and be drafted as the embodiment of the mathematical model.

Mathematical modelling is a very sophisticated (and therefore expensive) tool. The concept of *Function Analysis* requires us to focus on the functioning of analysed systems, while the modelling language is not so formal as mathematical modelling. The concept is believed to have been introduced by Lawrence Miles [2], a design engineer for the General Electric Company. His main idea was to force a designer to think of a system as a machine that performs a useful function for a user/customer (value analysis). As the embodiment, or function bearer, is more shadowed, this helps a lot to overcome mental inertia. The designed object is modelled not by a system of material bodies, but by a system of required functions. Although still very subjective and informal, the approach turned out to fill the gap between descriptions in natural language and mathematical modelling.

1.2. TRIZ Function Analysis

The same idea (of *Function Analysis* prior to sketching a new system) is fundamental for the Theory of Inventive Problem Solving (TRIZ), developed by Genrich Altshuller [3-4]. Although in a different form, Altshuller introduced certain modelling techniques for analysis and inventive design. Namely, there were: *Minimal Technical system* model ("Energy Source – Engine – … – Object") and *Substance-Field triples (Su-Fields)* model [5]. Again, the main enemy for improvement is mental inertia, the uncontrolled intention of professionals to materialize the design in the way "it has usually been". Engineers of Invention Machine [6] and GEN3 Partners Company [7] developed the classic TRIZ approach into more systematic algorithms that vary in detail and instruments, but both are based on F*unction Analysis*.

It is also worth mentioning that the idea of *Function Analysis* is very popular in the modelling of enterprise business processes, illustrated by the IDEF approach [8].

1.3. Trimming

To explain the basic principle of trimming an explicit illustration in the more formal analytical domain, *Functional Analysis* in mathematics, is provided. Say, we have an operator S of certain dimension N that maps inputs $\boldsymbol{x}$ to outputs $\boldsymbol{y}$:

$$S(\mathbf{x}) = \mathbf{y} \quad (1)$$

For example, S could be an operator of a differential equation or a transfer function of the N-th order. Let the quality (measure) of the operator be described by operator norm $||S||$; this norm can be aninput/output ratio (e.g. maximal gain). Also, let the number γ describes the upper limit for the qualitydeterioration.

If there is an operator S_r of a lower dimension r (i.e. $r < N$) that does the same mapping and satisfies the inequality:

$$||S - S_r|| < \gamma \quad (2)$$

Then operator S can be trimmed to the lower order operator S_r without quality deterioration. In this way, we can take advantage of (almost) the same function represented by a simpler operator. This process of simplification of a mathematical model is called “model reduction” and is widely used by those who seek less complexity or faster computations. In other words, trimming is the approach to reduce the complexity of the function model of technical systems without losing demanded quality.

In the context of Function Analysis, trimming is a similar manipulation trying to remove excessive/redundant elements that either cost a lot, contribute in a small amount or insignificantly to the useful functions, or have harmful functions as a side effect. Obviously, also in this case, the elimination (trimming) of these elements should not interfere the main function of the system; thus, not losing demanded quality.

1.4. Change propagation

As *Function Analysis* models describe the function representation of systems, trimming modifies the functionality and physical components within the system. The trimming process should initiate a series of changes within the system that eventually dies out; and, as a result, a new instance of the system emerges. Both the propagation of the changes and the quality of the (newly) obtained system are important aspects of change propagation in systems.

In [9-10], mechanical loaded systems are described by structures and ontologies that contain (among others): parts, functionality and links between parts. Based on these functionality and links, changes can propagate to other parts of the system. The parts themselves are described using 4 aspects: material, function, production process plan and geometry, as indicated in Figure 1. A change stemming from another part in the system will result in a change in one of the aspects of the part, which in turn may require changes in other aspects of the same part. For example, if more stiffness as functionality is required, either geometry or material can be changed. In turn, this will have an effect on the production process plan as well. When all aspects of a single part are updated, linked parts can be investigated to see if the change applied also affects their aspects.

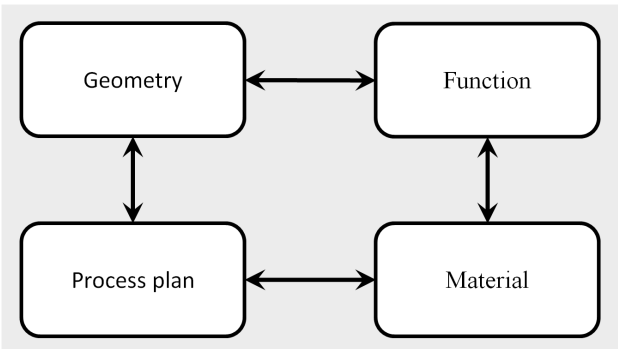

Fig. 1. Product aspect hierarchy to indicate change propagation on a part level [9].

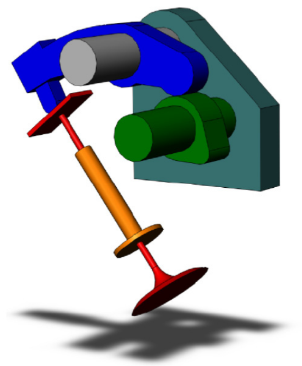

Fig. 2. CAD assembly of a cam-drive.

Although changes can propagate through systems in the manner described above, the quality of the resulting new system instance is not guaranteed. Consider, for example, the cam-drive of Figure 2. If the part that guides the valve (orange) is trimmed based on eco-design considerations, the functionality of this part could be transferred to the part that mounts the shaft (grey green). For the shaft mount this would result in a change of function and, based on Figure 1, this has an imminent effect on the geometry (flat to 3D shaped) and subsequently on the production process plan (e.g. laser cutting to casting). The resulting system has one component less, but additional analysis is needed to evaluate if the combination of changes is also an eco-improvement.

Both Panasonic in 2008 [11] and Toshiba in 2009 [12] developed a process where product evaluation was taken a step further. TRIZ was used to innovate and develop sustainable products, and Quality Function Deployment (QFD) was used to evaluate if the new and technical sound products also have a commercial appeal. Hence, ideal sustainable development is defined as products that score better on both rankings: sustainability and consumer appeal.

1.5. Research goal & Outline

Our goal is to introduce a methodology of function analysis into standard engineering design software, thus making the workflow more complete. The authors pursue to develop algorithms for automated trimming and function ranking functionalities for CAD software.

In this paper, we will introduce (partially automated) function modelling, function ranking and an algorithm by which these function models can be simplified (reduced in order) by trimming. A SolidWorks add-in is developed to demonstrate and validate these features.

The remainder of this paper is structured as follows. In Chapter 2 the application of function analysis in SolidWorks is presented. This is actually a short summary of a previous paper on this topic. Chapter 3 discusses the implementation of trimming in the SolidWorks add-in and in Chapter 4 the same is done for implementing function ranking. Chapter 5 briefly discusses the extraction of model hierarchy from the CAD data. Finally, in Chapters 6 and 7, the outlook and conclusions of this paper are given.

2. Function Analysis in SolidWorks

In a previous publication of this research [13], function analysis was introduced to SolidWorks as an add-in. Based on an existing CAD model, the software generates a function model in an automated manner. The software functions as follows:

1. The assembly of a CAD model is read. From this assembly, components and interactions between them are (automatically) detected and put into an Interaction Matrix. Hence, this matrix represents all interactions (functions) between components (parts). To find all interactions and fill the matrix, the software looks for dedicated CAD relations, known as "mates" in SolidWorks. Also, components that physically touch each other share a relationship; usually this is a "holds" or "guides" relation. After the automated population of the Interaction Matrix, the user can also manually add and remove interactions.
2. The interactions of the Interaction Matrix represent functions that must be defined. In some cases, when sufficient CAD detail is present (e.g. CAD metadata, "mates" information, etc.), automated function definition can be applied. In other cases, the user is prompted to define the intended function. Here, also a distinction in function performance between *basic*, *auxiliary* and *harmful* can be assigned.
3. From the Interaction Matrix a function model diagram is generated. This diagram shows a hierarchical structure of the components and the functions between them. The user can select components either from the original CAD drawing or directly in the function model diagram.

As mentioned in Section 1.1, such a function model overview is very insightful for designers, as attention is put on elements and functions, and not so much on the embodiment of function carriers. Thus, eliminating mental inertia. Also, the software helps to achieve a more complete and convenient workflow for design engineers as all is done within the CAD environment (SolidWorks). Finally, having this overview is a prerequisite for performing other TRIZ tools, such as trimming and function ranking. Automating these tools as well will be described in Chapters 3 and 4, respectively.

2.1. Software implementation

To demonstrate the powerful functionality of performing an automated function analysis directly from a CAD model, a practical test case is presented. In this example, a function analysis is performed on the cam-drive operating a valve, as was shown in Figure 2. This is actually the original CAD assembly of the cam-drive. Figure 3 shows the Interaction Matrix that is generated by the software based on the CAD assembly. In this case, 6 components are detected including 6 interactions.

From the Interaction Matrix, functions are defined. Depending on the CAD-data, from some of the interactions the functions are automatically detected, others require a user input. The user input dialog is shown in Figure 4. For instance, here the user is prompted to define the function between the shaft mount and the cam shaft, since they physically touch each other in the CAD model. After all functions are defined, the software generates the function model diagram. The resulting function model for the cam- drive model is shown in Figure 5. Generation is based on a target component, in this case the valve.

The function model diagram, as shown in Figure 5, is the starting point for trimming and function ranking functionalities. These functionalities are also implemented into the SolidWorks add-in software tools, as described in the next two chapters.

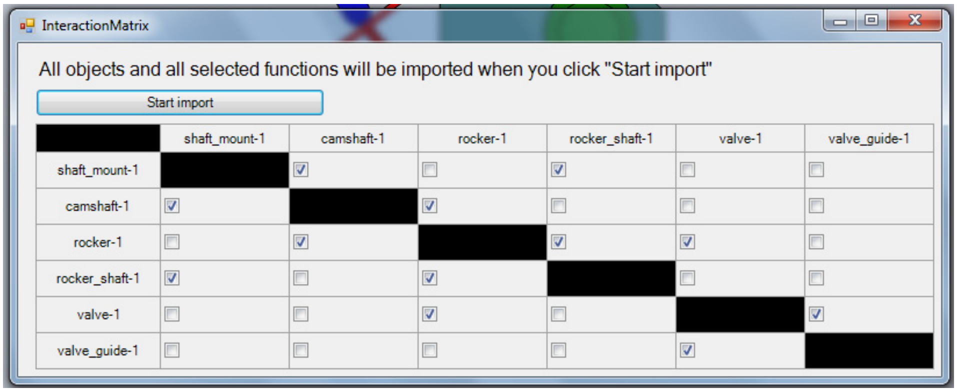

Fig. 3. Interaction Matrix of cam-drive.

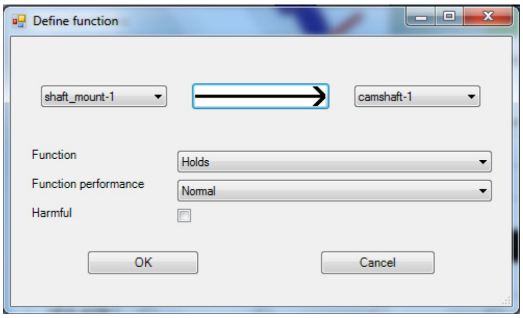

Fig. 4. User input dialog to define a function.

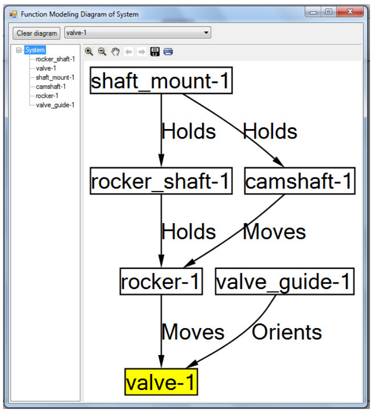

Fig. 5. Generated function model diagram.

3. Trimming in SolidWorks

Trimming is a method from TRIZ used to reduce the amount of system components without losing system functionality, as discussed in Section 1.2. The method is based on transferring functions performed by a component that should be trimmed to another component, preferably to the components where the function acts upon. If the designer succeeds in finding other components to perform this functionality, the component not performing any functions anymore can be removed (trimmed) from the function model without losing any functionality.

To perform trimming in a semi-automated way, a recursive algorithm is designed that performs this task on the component (selected by the user for trimming) and also on the components that perform one or more functions on the to-be-trimmed component. The process steps of this algorithm are shown in the flowchart of Figure 6.

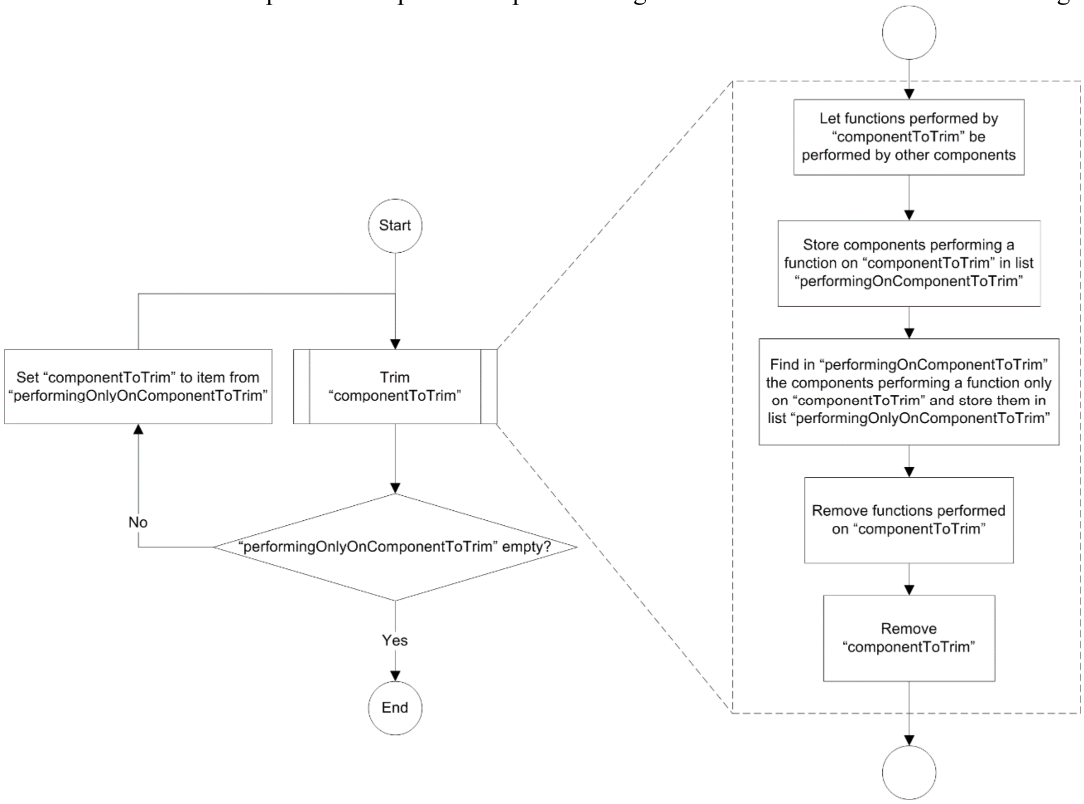

Fig. 6. Flowchart of the trimming algorithm.

The following steps can be observed in Figure 6:

1. For each function performed by the component-to-trim, the user is asked which other components could perform these functions. Subsequently, the functions are transferred.
2. The components performing a function **only** on the component-to-trim are stored in a list. If the component-to-trim is removed, the components in this list will become useless (obsolete).
3. All functions performed on the component-to-trim are remove, since these functions will also become useless (obsolete).
4. Remove the component-to-trim.
5. Repeat steps 1-4 for all components in the list of step 2 recursively. These components become the new component-to-trim.

This algorithm is called semi-automated, since it only performs the removal of components and transfer of functions. The user still has to manually select a component to start trimming and he / she has to select to which components the functions can be transferred.

As mentioned in Chapter 2, the software can propose functions based on CAD metadata; for instance, the components' names or their interaction type (which "mates" they share). To assist the user with selecting candidates to where functions can be transferred, the system can be reversed. Instead of proposing a possible function for a selected component (pair), a component is proposed for a selected function. For instance, a component can be proposed by looking up (the beginning of) component names or search CAD metadata of components. Note: this reversed proposal system has not yet been implemented into the software tool.

4. Function ranking in SolidWorks

Function ranking is the concept of ranking functions based on their level of usefulness. This is an addition to the existing classification of functions such as 'useful' and 'harmful'. Ranking is done by first selecting a "target component". This component, within a useful system, is *the* component that performs the system's main function. Furthermore, functions, within a useful system, that directly perform a useful function are called 'basic functions'. Other functions, supporting the basic functions (indirectly), are called 'auxiliary functions'. Finally, harmful functions are simply ranked as 'harmful functions'.

This is shown in Figure 7. Here, the software tool has performed function ranking based on the selected (highlighted) target component (i.e. valve-1). Basic functions, denoted B, are functions performed on the target component. The other functions are either auxiliary, denoted A, or harmful, denoted H and shown in red. Depending on the level of closeness (indirectness) of the auxiliary function to the target function, they are also ranked by number: A1, A2, etc.

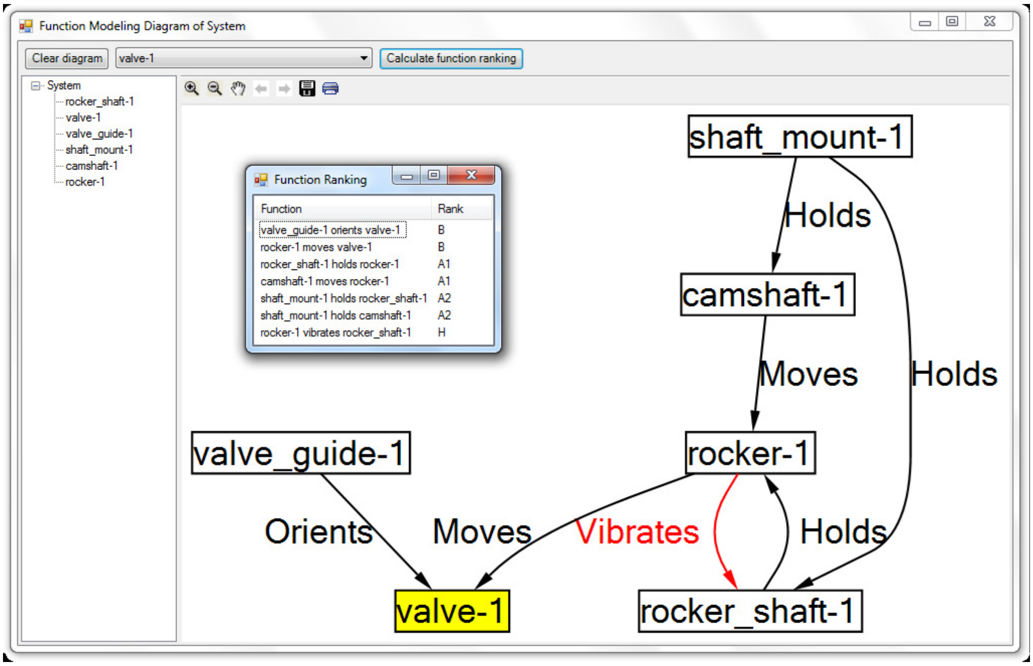

Fig. 7. Function ranking for the cam-drive example; valve-1 is selected as 'target component'.

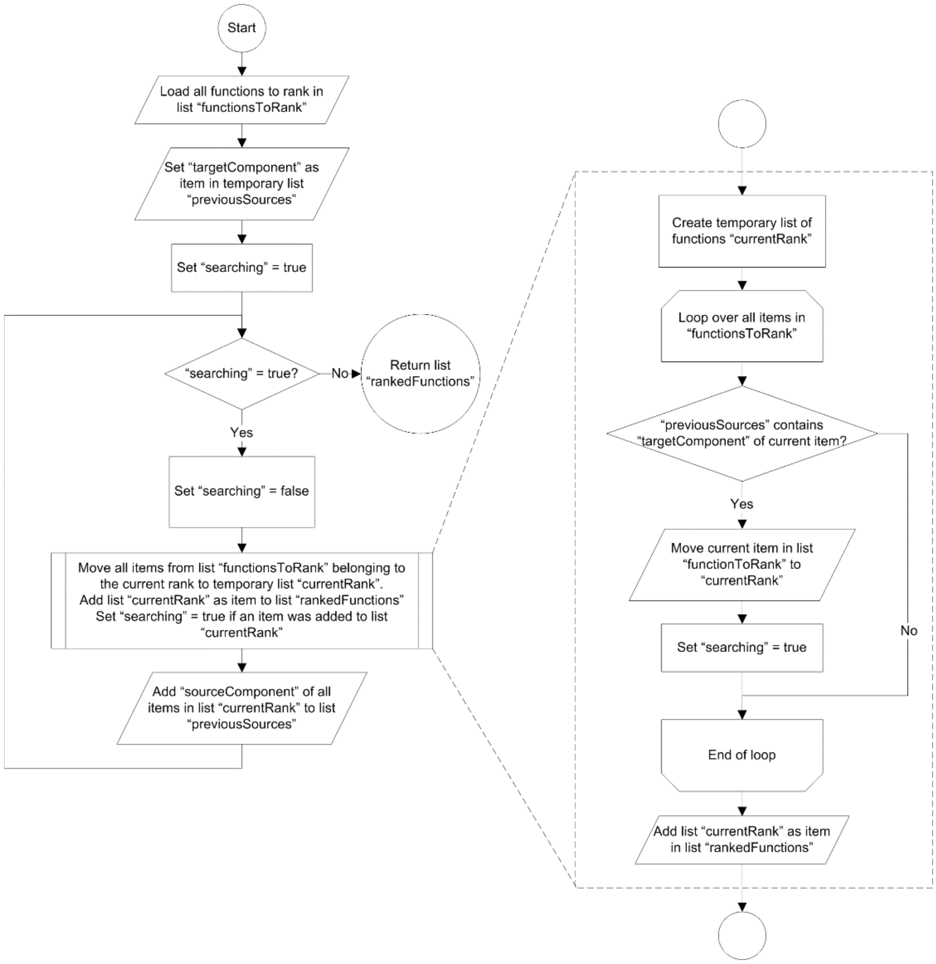

Fig. 8. Flowchart of the function ranking algorithm.

The algorithm behind automated function ranking is shown in Figure 8. It operates as follows:

1. Load all functions of the function model as items in a list called "functionsToRank".
2. Create a separate list in which function lists belonging to the same rank are stored. This list is called "rankedFunctions".
3. Set the target component of the system as item in a temporary list of starting points from where to look for functions of the next rank. This list is called "previousSources".
4. As long as functions belonging to the previous sources list are present, loop through the following:
   a. Create a temporary list called "currentRank".
   b. Move all functions from "functionsToRank" to "currentRank" if they belong to the current rank. Functions are detected as belonging to the current rank if they are performing on an item from "previousSources". Add "currentRank" as an item in "rankedFunctions".
   c. Set "previousSources" to be the components performing the functions in "currentRank" so that they serve as starting points for the next iteration.
5. Output the list "rankedFunctions".

Function ranking offers the user a quick overview on the structure of a system and on the importance distribution of functions. After a function model diagram is generated and the system's target component is selected, the only action required by the user is to click the "Function Ranking" button. Hence, this is an analysis tool rather than a modification tool.

5. CAD model hierarchy extraction

The add-in as presented in Chapter 2, already offered the possibility to create a hierarchy in the function model manually. In the current version, the hierarchy as defined in SolidWorks by the use of sub-assemblies, sub-sub-assemblies, etc., is automatically copied into the function model as part of the usual workflow. The algorithm used for this is a recursive algorithm that iterates through the nodes in the SolidWorks feature manager tree. For each node in this tree, a node in the system tree of the function model iscreated.

The advantage of extracting the CAD hierarchy into the function model is that the user can now also view the functional relations at different levels of detail. In the end, this would allow design engineers to iterate quickly between low and high level functions while preserving an orderly coherence.

6. Outlook

Continued globalization and fierce competition puts constant pressure on the product design process that a company need to follow. In recent decades, CAD software allowed companies to increase their engineering efficiency tremendously, which allowed them to put products on the market in a shorter time span. The CAD software was most useful in gaining time during the product detailing and production phases.

In the future, this should also encompass the product innovation process, which is traditionally more to the front. Ideally the CAD assembly can be generated (automatically) from a function model diagram and design engineers can quickly move the detailing phase. Hence, the envisioned computer support tool can realize the blueprint for the latter design phases automatically from the initial product functions on an abstract level.

7. Conclusions

In this paper a software tool has been presented that guides and supports design engineers in their innovation process. A function model diagram is automatically generated from CAD assembly data. Functional modelling is based on TRIZ theory of Function Analysis. Design engineers can use the function model diagram for trimming and function ranking purposes to improve their product. Trimming and function ranking functionalities are also part of the software tool and act in a semi-automated manner. Both functionalities are demonstrated in this paper.

Design engineers can jump from product detailing to product innovation activities without having to switch software tools or convert datasets, providing better support for the complete workflow. Model hierarchy is also extracted from the CAD assembly data and allows designers to iterate between levels of abstraction easily. Altogether, they can progress more quickly through their product design phases, which, in the end, results in shorter lead times and a faster time-to-market.

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