INTEGRATING TRIZ FUNCTION MODELING IN CAD SOFTWARE

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Key words: Function Modeling, CAD, software, innovation, TRIZ.

1. Introduction

This paper gives a short overview of TRIZ, Function Modeling, Computer Aided Invention (CAI) software and Computer Aided Design (CAD) software. It explains the link that is missing between CAI and CAD software. A summary of the research in this field is given. Furthermore, a proposal for the integration of CAI and CAD software is given along with the description of a SolidWorks add-in prototype that realizes this integration. Finally, a future vision is given how Function Modeling could be used as a design tool instead of an analysis tool.

1.1 Function Modeling

Nowadays, many technical systems are described by models that can be visualized using diagrams. Physical properties can be linked to the objects in the models. This enables, for instance, the simulation of electronic circuit schemes computer software or Matlab Simulink block diagrams representing the mathematics of a general dynamic system. Most function diagrams are graphical representations of material flow or information flow, where the components perform some processing steps on the input. Such diagrams can be from a managerial perspective where the objects can be e.g. production stations in a factory or corporate departments in IDEF0 diagrams [1]. Diagram types that can show the sequence of process steps in time are e.g. Gantt-charts [2] for project management or UML Sequence diagrams [3] for software engineers.

1.2 TRIZ and Function Modeling in TRIZ

TRIZ is the Russian abbreviation for a set of theories and tools for systematic and inventive problem solving. It was developed since the 1940s by Genrich Altshuller and his colleagues in the former USSR [4-5]. Next to ‘Classical TRIZ’, many improvements and new methods have been contributed. One of the new methods, that has been added, is Function Modeling. Unlike other function model types, TRIZ Function Modeling diagrams [4, 6] do not represent flow: there is no input / output; the models rather show the influence of source objects on a parameter of target objects. Furthermore, there is no time-dependency by default.

The use of this Functional Modeling is to describe a (technical) system in an abstract way: by describing the situation in terms of functions and changes of parameters. Psychological inertia is removed, because unnecessary information which could distract the engineer is removed, allowing the engineer to focus on the most efficient way to perform the needed function on the target object.

Function Modeling is usually performed before other TRIZ tools for extended analysis and system modification can be applied. These tools are for instance trimming, contradiction analysis and cause-effect chain analysis. Compared to other TRIZ tools, like for instance contradiction analysis and Su-Field modeling, Function Modeling is one of the most formal of the modeling techniques in TRIZ. Although being much less formal than mathematical modeling, Function Modeling is still a big leap describing technical systems compared to describing them in natural language.

1.3 TRIZ and CAI software

Currently, there are many stand-alone software packages based on TRIZ and TRIZ-like methods that deliver design support for, for instance, analysis, contradiction solving, idea generation and knowledge databases [7-8]. This software will be referred to as Computer Aided Invention (CAI) software. However, these tools are separated from typical CAD software packages: data is not stored in a central place (changes in the CAD domain are not synced with the CAI domain) and results from TRIZ(-like) software cannot be used automatically in CAD systems.

1.4 CAD-CAM-CAE tools

CAD tools have been developed in many forms and for many purposes. Mostly the designer is assisted during the detailing and production phases of product design. For instance, Computer Aided Process Planning [9] based on product features or what-if synthesis support tools [10] for embodiment design.

Modern CAD software typically integrates with multi-physics simulation tools like Computer Fluid Dynamics (CFD) or structural analysis. CAD tools can even help in the geometrical design (optimization) phase by means of e.g. automated routing for printed circuit boards based on an electronic scheme. Research is done on topological optimization by means of CAD systems [11]. SolidWorks is one of these 3D CAD software suites that combine, amongst others, geometrical modeling, thermodynamic analysis and structural analysis. Some universities, like Saint Petersburg State Polytechnical University and University of Twente, teach their students in using it.

According to a market research by Vleeschhouwer from early 2010 [12], SolidWorks users made up for about 22% of the active commercial 3D CAD users at the end of 2009. Other main players in this area are CATIA and Pro/Engineer. It is assumed that this market share will not change dramatically in the near future.

1.5 State-of-the-art

In the past, Dassault Systèmes provided a TechOptimizer add-in for CATIA v5 to define Function Models, but the functionality of that software was limited: according to its user guide, the user had to manually define the Function Model and manually link the CAD parts to the components in that Function Model.

There are some patents about generating objects from a TRIZ Function Model, e.g. from ImpactXoft [13], but currently there is no software publicly available based on these patents. To start integrating CAD and CAI software, there must be a common data model. According to a paper in 2004 by Cascini [14]: “The goal of integrating CAI and PLM systems requires the development of a common platform for product data exchange: in other words all these tools must share the same product model.” The authors of this paper believe that the TRIZ Function Model is a good example of such a shared model. It can act as the basis of integration of the design domain and the innovation domain.

In 2001, León-Rovira [15] started research in this field by researching the generation or improvement of physical designs in CAD systems based on Functional Models. However, this research is not finished yet and there is currently no other integration between CAD systems and TRIZ technology: neither analysis nor synthesis based on TRIZ can be performed straight from any CAD package.

1.6 Problem setup and research goal

Although the aforementioned tools and methods are aimed at improving engineering software, there are still a few points that show room for improvement or points that prevent utilization to the full extent.

Firstly, the CAI software suites that provide Function Modeling as part of a larger workflow, like GoldFire Innovator, are usually very expensive. This makes them mainly attractive for larger companies. Secondly, all available CAI suites are stand-alone. They provide no integration with other engineering software. Hence, there is also no synchronization with other engineering software, not even import / export functionality. However, engineers in industry are often forced and trained to use CAD software for their product design. The lack of integration means that they have to alternate between two separate applications (CAD and CAI) if they want to use Function Modeling. This situation lowers productivity because learning to use two separate applications and to copy data back and forth between them costs a lot of time. Finally, the number of engineers that use TRIZ today is still very low. In 2008 one of the managers of Invention Machine estimated [16] that only one percent of the world’s engineers was exposed to TRIZ.

The aim of the authors is to lower the threshold for engineers of using Function Modeling together with their CAD systems. Therefore, the goal of this research is to propose a set of principles for the integration of TRIZ Function Modeling in CAD systems and to demonstrate these principles using a SolidWorks add-in. SolidWorks was chosen because of its market relevance (see Section 1.4) and because it is software that is used at the universities of the authors. However, the principles of this research should be applicable to any CAD software suite.

This study focuses on the research of integration principles and aims to deliver a proof-of-concept. The proposed principles can be validated in a separate usability research, for example to prove the increased ease of use or the increased productivity.

2. Solution suggestion

To make Function Modeling more attractive for users of CAD software, the authors assume that the following points should be taken into account:

- There should be integration between Function Modeling and CAD software
- The user should preferably not need to alternate between his CAD and CAI software

During this study, the ways how the user can be assisted were researched at the following points:

- Assist the user in creating a Function Model from scratch
    - Detect interactions
    - Propose functions
- Assist the user in maintaining the Function Model
    - Allow for creating a system hierarchy
    - Allow for editing
- Assist the user with knowledge about functions

Each of these points will be discussed in the following sections.

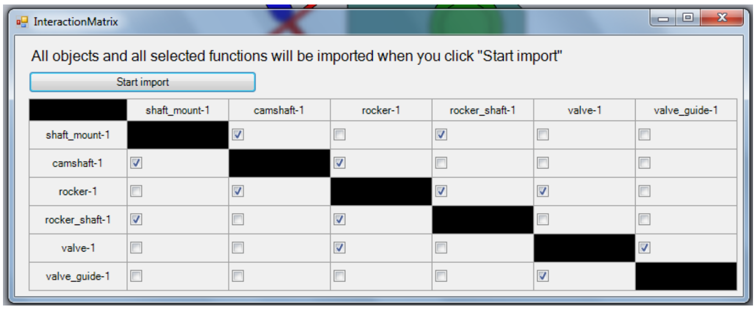
2.1 Generating a Function Model from an assembly

Traditionally a Function Model of an existing system is created by first deriving an Interaction Matrix and subsequently drawing functions between all components that have an interaction in the Interaction Matrix. This workflow is not changed to make the workflow easy to recognize for people that already are familiar with Function Modeling.

2.1.1 Interaction Matrix generation

To assist the user, the SolidWorks add-in can automatically generate the Interaction Matrix (Fig. 1). To make this possible, interactions need to be detected somehow. As in traditional Function Modeling, two parts are said to be interacting if they touch. This criterion is still used, but it is chosen to be extended by indicating an interaction if the two components share a relation defined in the CAD software. These are known as ‘Mates’ in SolidWorks. The reason for this choice is that this makes it possible to recognize interactions between components that might perform a certain function without touching in the CAD system. Furthermore, the add-in is able to propose a type of function for each interaction based on the type of relation. This will be discussed in Section 2.1.2.

All the detected interactions are shown in the Interaction Matrix. The user can add or remove interactions and hereafter start defining functions (Fig. 2) for each interaction.



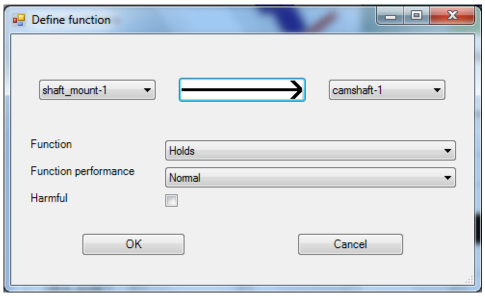


Fig. 1. Interaction Matrix

Fig. 2. Define function dialog

2.1.2 Function proposal

The second part of user assistance is the proposal of functions. When the user wants to add a function to the Function Model, there are two components for which the function will be defined: a source component and a target component. Based on these two components, a function is proposed by selecting the proposed function in the Define function dialog (Fig. 2).

As long as there is no awareness or Artificial Intelligence in CAD systems, it is very hard to let the software recognize which function is represented by the geometry of a part. Some research has been conducted in this field [17], but there is no available implementation in CAD software yet. Therefore a system is developed that recognizes functions based on the following criteria:

1. If there is a function defined in the metadata in the model file of the source component of the function (i.e. in the CAD Component): propose this function. In SolidWorks, this metadata is labeled a 'custom property'.
2. If the name of the source component in the Function Model suggests a function (to ensure that it also works for components without a representation in the CAD domain): propose this function. For example, a component of which the name starts with 'screw' could provide the function 'holds'.
3. If the interaction member components share a relation that unambiguously suggests a function (a 'Gear mate' probably provides the function 'rotates', but the function of a 'Parallel mate' is ambiguous): propose this function.

To adapt the function proposals to the user's needs, the user can change the metadata in SolidWorks parts, change the functions that will be proposed for certain beginnings of component names or change the links between interaction types and function proposals.

2.2 Maintaining and synchronizing the Function Model

Through the Function Model diagram interface (Figure 3), the user can directly interact with the Function Model. Besides the trivial loading, editing and saving of the Function Model, the user can also restructure the hierarchy of the Function Model (left hand side of Figure 3). Finally, the user can be assisted by responding to his actions in the following ways:

- When the user adds or removes a component to or from the CAD assembly, the add-in will propose to add or remove it from the Function Model too.

- When selecting a component in the Function Model that is linked to a component in the CAD assembly, the add-in will select the linked component too.

Other responses to events can also be implemented – see Section 2.5.

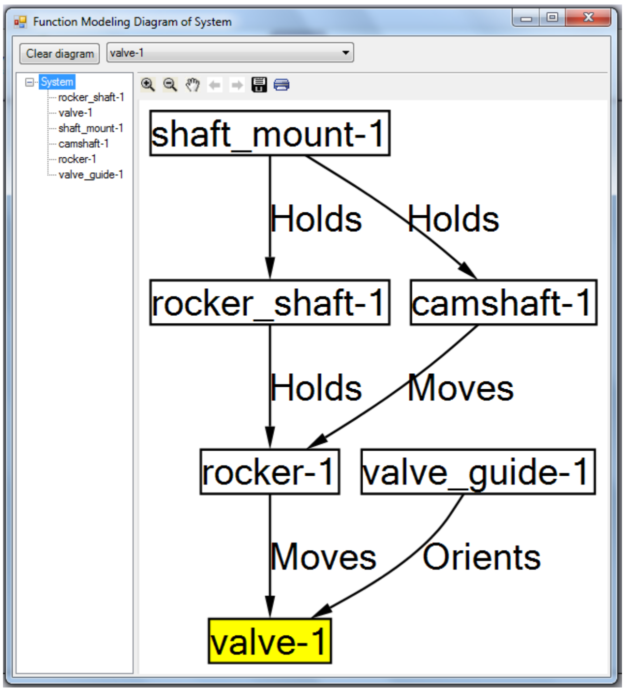


Fig. 3. Function Model diagram

2.3 Assisting the user with function implementations

The last area where users can be assisted is to store knowledge, which is linked to the context of functions. This knowledge can involve a list of phenomena which can perform certain functions, so that the user can ask the software tool to propose some of these phenomena for a specific function. In the developed add-in prototype, the proposed phenomena are linked to Google Scholar. This allows the user to search for additional information about the selected proposal, but other linking options like with patent databases can also be envisioned and implemented.

2.4 Data storage and integration with CAD software

Since it is very difficult to change the working of CAD software itself, the add-in is built like a layer around the software. Also, the SolidWorks data format is not flexible enough to transfer all data from a Function Model to SolidWorks (other CAD software was not evaluated on this point). For add-ins it is only possible to read and write geometrical data and metadata from the SolidWorks files. Therefore, the add-in will create one extra file per assembly for which a Function Model is made. This means that the data is not literally shared between SolidWorks and the Function Modeling add-in, but that the Function Modeling add-in manages all relational data. However, this is only an implementation detail that depends on the CAD software with which the integration is done.

2.5 Features that could also be added to the add-in

- Recognize more interaction types, for example from SolidWorks Simulation (where features like gravity, motors and forces can be modeled)
- Recognizing the assembly hierarchy from the CAD software (Feature Manager tree in SolidWorks)
- Ability to recognize patterns in component names to propose functions.
- Propose to add and remove a component to and from an assembly when that component is added to or removed from the Function Model
- Assist in proposing candidates to trim based on the fact whether they perform a function directly on the target component ('basic functions') or on another component further away from the target component.
- Propose implementations of functions by component combinations or sub-assemblies.
- Make phenomena search queries dependent on if the function is harmful and on the intensity of the function to allow for more detailed search queries.

3. Conclusions and recommendations

Currently, there is no integration of CAI and CAD software. Learning to use two separate software systems and copying data between them costs precious time that could be saved when systems would be integrated. Therefore a set of integration principles has been developed that assists the user in creating and maintaining Function Models based on CAD assemblies. Interactions between components can be derived from assemblies in the CAD software, functions can be proposed for interactions, and implementations can be proposed for functions by means of physical phenomena.

The developed SolidWorks add-in prototype demonstrates the discussed principles and the researchers will continue this study by researching the proposed features of Section 2.5. Furthermore, it is necessary to perform a usability study to prove the merits of the principles that resulted from this research.

Finally, Function Modeling is usually the beginning of a larger workflow (e.g. Trimming can be the next step). Without providing integration with the rest of the workflow, the integration cannot be called 'complete' because users then still need to use a separate tool for the remainder of their workflow.

3.1 Future vision

With the continued increasing globalization and shorter lead times, companies are constantly putting pressure on their product design processes. The last decades, CAD software has tremendously increased the engineering efficiency, especially during the product detailing phase. To further improve efficiency, both automated support for the conceptual design phase and integrated support for the conceptual and detail design phases must be developed. For instance, an assembly could be generated from a Function Model drawn by the user.

Instead of transferring product details to a Function Model in an automated manner, the opposite direction is much more interesting for design purposes. The envisioned support tool is able to generate a blueprint for the latter design phases, based on a Function Model. For instance, complete assemblies can be synthesized based on a developed Function Model. This allows engineers to quickly move to the detailing phase after designing the Function Model.

4. Acknowledgements

This paper was written as a part of an internship, hosted by the St. Petersburg State Polytechnical University, for the study Mechanical Engineering at the University of Twente. The authors would like to thank both universities for making this exchange possible.

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