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DESIGN CATALOGUES AS KNOWLEDGE MANAGEMENT AND EDUCATIONAL TOOLS IN MICROSYSTEM ENGINEERING DESIGN

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Abstract

Educating engineers to cope with design problems requires appropriate didactic means and methods [1]. For microsystem engineering, the finding of optimum educational resources is still a challenge, due to the multidisciplinary nature of its field [2]. Microsystems are characterized by interdisciplinary spatial and functional integration, a high level of heterogeneity, elevated complexity, relative autonomy and a certain ability to take decisions. Consequently, the designer develops non-static systems, which demands special design tools that are not yet available. This paper discloses the development of a computer aided knowledge management tool for microsystem engineering design that is based on the design catalogues method. It is foreseen as an effective educational tool and as adequate for promoting a rapid integration of engineers with no microsystem technology background in multidisciplinary design teams. The development of knowledge bases in the form of design catalogues allows not only a structured assortment of proven solutions to specific problems at different design levels, but also the straightforward transmission of experience with educational purpose.

Keywords: engineering design education, microsystems, micro electro-mechanical systems, knowledge management, design methods

1 Introduction

Developing innovative products and services is a business challenge. Engineering design is the essence of the product innovation process and therefore a key factor to gaining a competitive advantage. In the first cycle, it consists of potential finding, product finding, business planning and concept designing. These knowledge-intensive tasks require a management strategy if expertise and creativity are to be successfully exploited as productive resources.

This requirement stimulated the appearance of systematic design, which meanwhile became state of the art in the development of engineering systems in the "macro world". From machines to mechatronic systems, the principles of methodical design have been elaborated and published in several guidelines, e.g. [3], [4], [5], [6]. To the contrary, in the "micro world", basic rules are currently being developed and a lack of scientific tools prevails [7]. Today, the main research effort in microsystem engineering continues to be the improvement of miniaturization and manufacturing processes, while systematic design is still often understood as only the implementation of CAD and FEM software.

Creativity and specialized knowledge are the innovative potentials of microsystems industry, research and education. Thus, they should be managed and systematically directed, which implies the creation of dedicated tools.

An adaptation of design catalogues as a synergetic integration of the engineering design and knowledge management theories could support the incorporation of systematic design into microsystem engineering and result in reduced lead times and costs.

Furthermore, the integration of design catalogues methodology with information technologies could fulfil the multidisciplinary requirements of microsystem engineering for knowledge management, life-long education and self-learning. Some computer-based educational tools have been developed to deal with complex learning issues in a multidisciplinary approach, for example "PharmaPac" a web-tool for students of pharmacology to learn from clinical situations [8] and there are also sources for methods and software for supporting e-learning, such as the Center for Innovative Learning Technologies [9], however, implementations based on the design catalogue systematic are available only for non-multidisciplinary knowledge fields, for example "eKat", a catalogue-system for mechanical engineering [10] and the "Internet-based Design Catalogue for the Shaft and Bearing" [11].

1.1 Challenges of microsystem engineering design and education

Microsystems represent a great opportunity to innovate through micrometer-size three-dimensional components that are capable of handling electrical and non-electrical signals in sensing, processing other actuating functions. They also offer the possibility of improving already existing products through novel functional and spatial integration, miniaturization, decentralization, autonomy, and modularity. However, microsystems simultaneously present the challenge of overcoming complex multidisciplinary interactions, sophisticated interfaces, intricate communications, complicated control, and refined physical and chemical effects of the micro-world.

Besides the technical opportunities, microsystems industry shows important economic potential. A 68 billion dollar world market is estimated for microsystems in 2005 [12]. A continuous expansion of the already existing applications in automotive, automation, aerospace, health care, consumer products, telecommunications and security industries, among others, is expected. Profiting from this is a challenge. Specially educated individuals with microsystems technology curricula are needed. In Europe, a current lack of researchers, engineers and technicians with such a background has already attracted the attention of industry and government [13].

Educating engineers to deal with this situation requires effective didactic means. A knowledge-based tool is necessary to share experience and support creativity during the microsystem development process. Such instrument should facilitate a structured transmission of knowledge in order to promote a rapid integration of engineers with no microsystem technology background in multidisciplinary design teams. It also should support the education of new designers at universities, colleges and institutes of technology. Additionally, the tool should offer both trained and inexperienced engineers a source of information for life-long learning.

These challenges can be synthesized in the following research questions:

How can microsystems design knowledge be systematically captured and reutilised to enable a flexible and efficient product development independent of the professional and methodical background of the designer?

Is it possible to cope with heterogeneity and interdisciplinary complexity in designing microsystems with the implementation of computer aided tools?

2 Research Approach

The assumption was made that implicit knowledge, or the totality of understanding and abilities an individual can apply to solve tasks and problems, is transferable when documented, e.g. registered and structured into explicit knowledge.

Established engineering design methods were reviewed to determine which one could be adapted to the interdisciplinary nature of microsystem design, because as illustrated in Figure 1, several engineering disciplines take part in the design process.

For the selection of the adequate method, careful consideration was given to the stipulation of being able to handle various types of knowledge at distinct levels of abstraction. Particular interest was taken in the analysis of potential for dealing with physical effects, working principles, principle solutions and system components with their interrelationships.

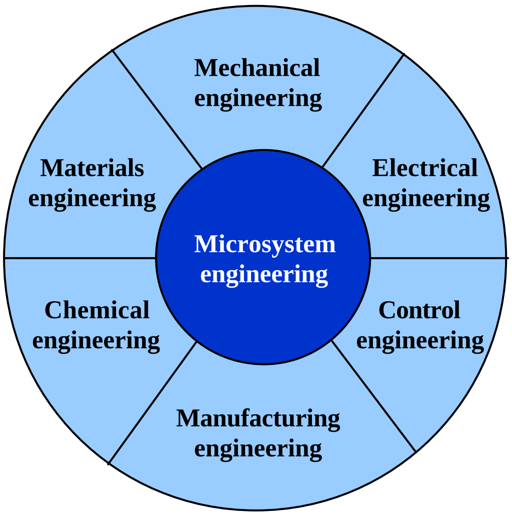


Figure 1. Multidisciplinary nature of microsystem engineering

Research was carried out to identify a computer-aided method that was able to store, structure and retrieve information in a non-linear way, thus matching the non-linearity of the microsystem design process. The property of being capable to organize knowledge in interlaced topological structures, as the human brain seems to do it, was crucial.

The selected engineering design method was integrated with the corresponding computer implementation into a tool that allows one to save, structure, retrieve and transfer expertise.

As an experiment on the viability of the selected methods, a miniaturized inclination sensor will be systematically developed.

3 Results

Design catalogues are by definition discipline independent [14]. Discipline independence matches the multi-disciplinary nature of microsystems. Moreover, design catalogues have proven in different engineering fields that they can contain heterogeneous knowledge, due to their problem-oriented accessibility not only to objective data, but also to solution suggestions, examples, methods and procedures. Therefore, they were found to be adequate for the purposes of this research. Nevertheless, the selection of design catalogues as knowledge management tool implies the problem of structuring the information contents in an optimised form for microsystem engineering. A method for structuring knowledge and supporting its retrieval is *Indexing*.

Ahmed and Wallace have proposed an empirical indexing method that can be adapted for structuring the classifying criteria of design catalogues for microsystem engineering. It categorizes design knowledge in the aerospace industry into four groups: process; product; functions and issues [15].

The group "process" contains the process itself, e.g. calculations or brainstorming. The index "function" encloses nouns and verbs that through combination fulfil the functions of particular components or assemblies, for example secure blade or withstand pressure. The category "Product" includes knowledge about specific elements, e.g. blade or turbine. The index "issues" comprises material like unit cost or weight.

This indexing structure was modified like shown in Figure 2. The index "process" was separated into two different categories: "process" and "operation". "Process" remains containing knowledge about the design process itself. "Operation" consists of object-related knowledge, e.g. calculation procedures, design rules or rules for building *function structures* [16].

Because of the fact that in microsystem design, the knowledge about system components is still under construction and therefore not so mature like the knowledge about machine elements in machine design, a more abstract classification was used instead of "function". The index "solution" substitutes "function" and includes additionally *generally valid functions* [16], e.g. store, change or connect. Generally valid functions together with nouns can represent system functions in a conceptual phase. These functions are task-related, for example "store fluid" or "change voltage".

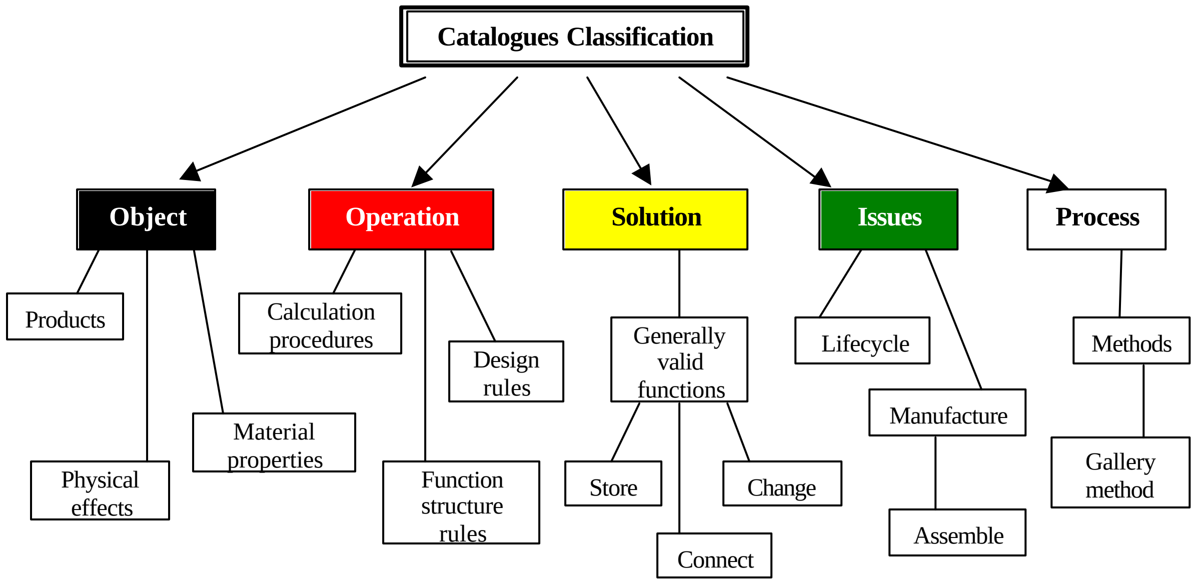


Figure 2. Indexing of the catalogues

The category "product" may be useful in embodiment design of machine elements. However, in microsystem engineering, a more abstract classification is preferable. Thus, it was substituted with the index "object" that contains function-independent knowledge about physical effects, material properties and general technical information. Nevertheless, the knowledge from index "object" through rules from "operation" may result in a "solution" that can be added as product in the category "object". This constitutes for the catalogues the ability to generate new knowledge. For example, information about the piezoelectric effect can be used to find the optimal piezoelectric material that with the rules for electromechanical conversion maximizes the function of converting a voltage into mechanical deformation. The gained solution represents for the system new knowledge about piezoelectric microactuators.

The index “issues” remains as it was originally presented.

Suggested taxonomies for the depicted indexes have been described widely in the literature, see for example [15] and [16].

Today, requirements for a multi-disciplinary knowledge management tool are: understanding what information needs to be recorded, possibility of a real time capture of new generated knowledge, and universal accessibility [17]. Further required functionalities are:

- availability of comprehensive knowledge, or, at least, the most essential one
- ability to expand
- rapid problem-oriented access to accumulated knowledge
- fast overview of all possible solutions for a particular design problem within the context of specific classifying criteria
- application independent of specific discipline or company
- Compatibility with conventional design procedures

Hypermedia method, defined as non-linear multi-modal knowledge representation and usage [18], was found ideal for satisfying these conditions through a computer-aided implementation using modern data processing technologies [10]. However, a case study from Del Rey-Chamorro and Wallace showed that designers prefer design information on paper format to electronic format, because they feel that current tools are not aligned with their way of working, constraining the information flow [19]. Nevertheless, they found in the same study that designers use a navigation and cross-referencing strategy to search information when they access unfamiliar documentation, but once they get used to the document structure the consultation succeeds by browsing. Therefore, for the goals of this research, a Web browser was selected as the visualisation program. This technology allows the deployment of the mentioned search strategies, facilitating the access for both novice and experienced designers. Figure 3 illustrates the user interface.

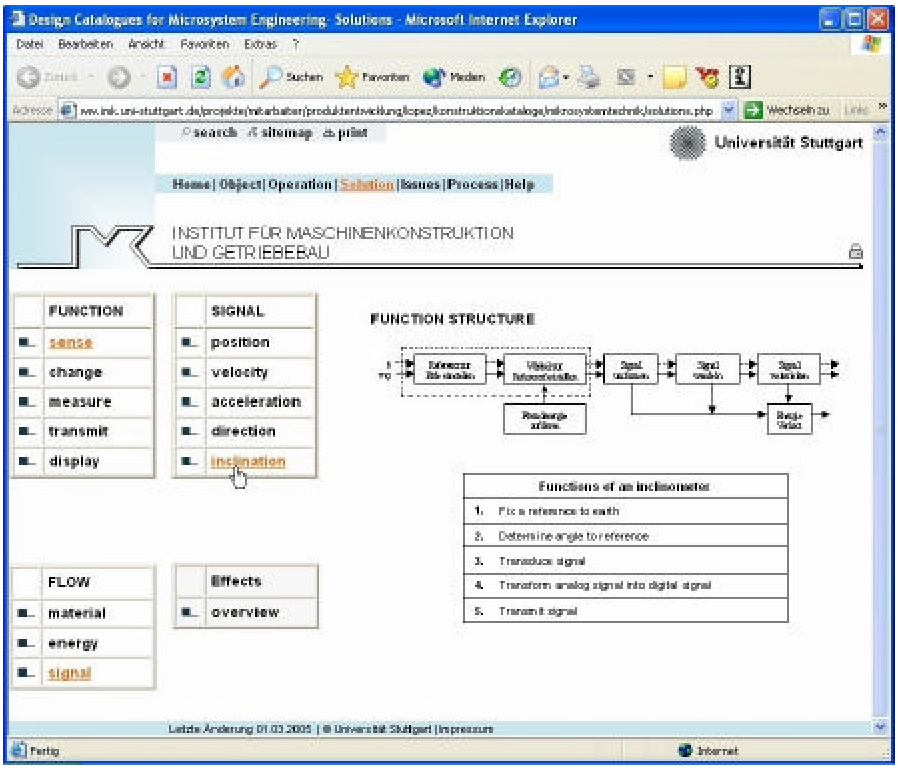


Figure 3. Hypermedia design catalogue – User interface

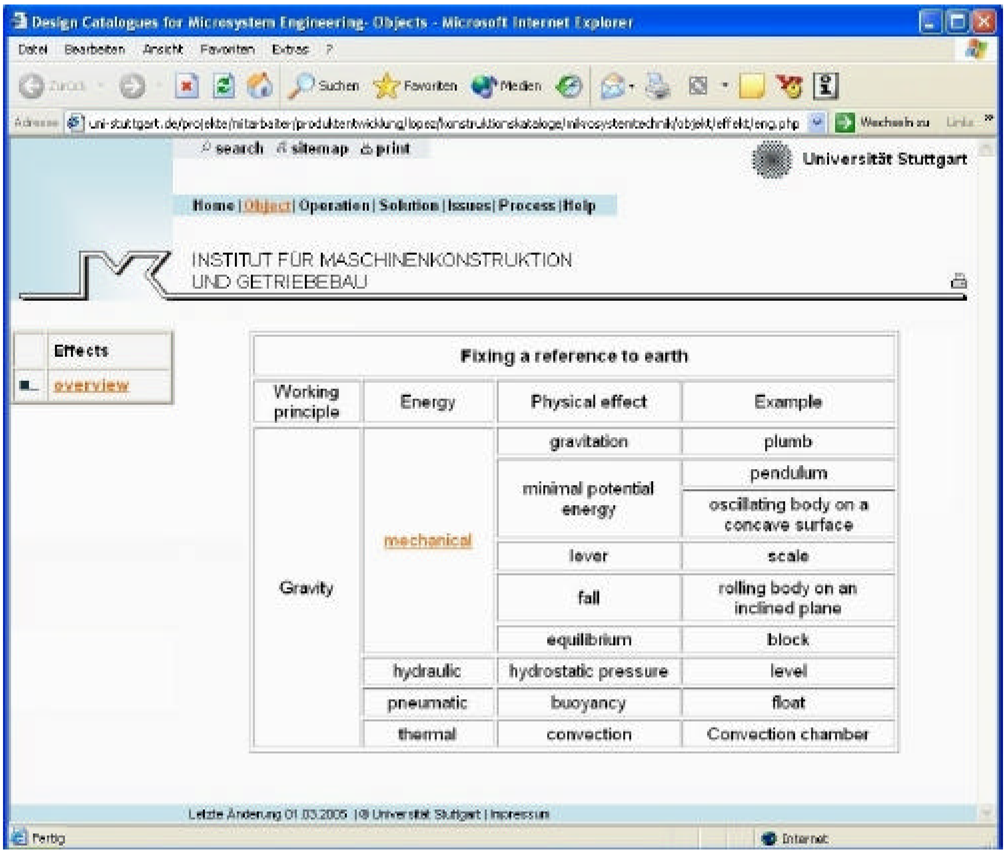
The developed design catalogues and the hypermedia method are integrated using Web technologies. Extensible Hyper Text Mark-up Langauge (XHTML) is utilised for software independent text and multimedia content structuring. The information layout and formatting of the contents is controlled with Cascading StyleSheets (CSS).

Extensible Mark-up Language (XML) is used for designing specific data for this application. Interaction with the user is achieved through JavaScripts and the access to databases and their manipulation with Structured Query Language (SQL).

To enable a dynamical edition of content, as well as its updating and expansion, Common Gateway Interface Scripts (CGI-Scripts) will be implemented.

In the catalogue user interface of Figure 3, there is a view of the solution module. It is shown how after selecting a *flow* and a *function*, e.g. "sense signal", a menu containing already stored types of signals emerges. A mouse-click on "inclination" activates the visualisation of the most simple corresponding *function structure*, in this case "sense inclination signal". The selection of a sub function, for example "fix reference to earth", and a click on the option "overview", open a second window including *working principles*. The overview is illustrated in Figure 4.

The user can look for deeper knowledge clicking on the options. Figure 5 presents the solutions to the function that are based on mechanical energy. Higher levels of detail come into view choosing one of the available abstractions.



Fixing a reference to earth			
Working principle	Energy	Physical effect	Example
Gravity	mechanical	gravitation	plumb
		minimal potential energy	pendulum
			oscillating body on a concave surface
		lever	scale
		fall	rolling body on an inclined plane
		equilibrium	block
	hydraulic	hydrostatic pressure	level
	pneumatic	buoyancy	float
	thermal	convection	Convection chamber

Figure 4. Hypermedia design catalogue – Overview of working principles

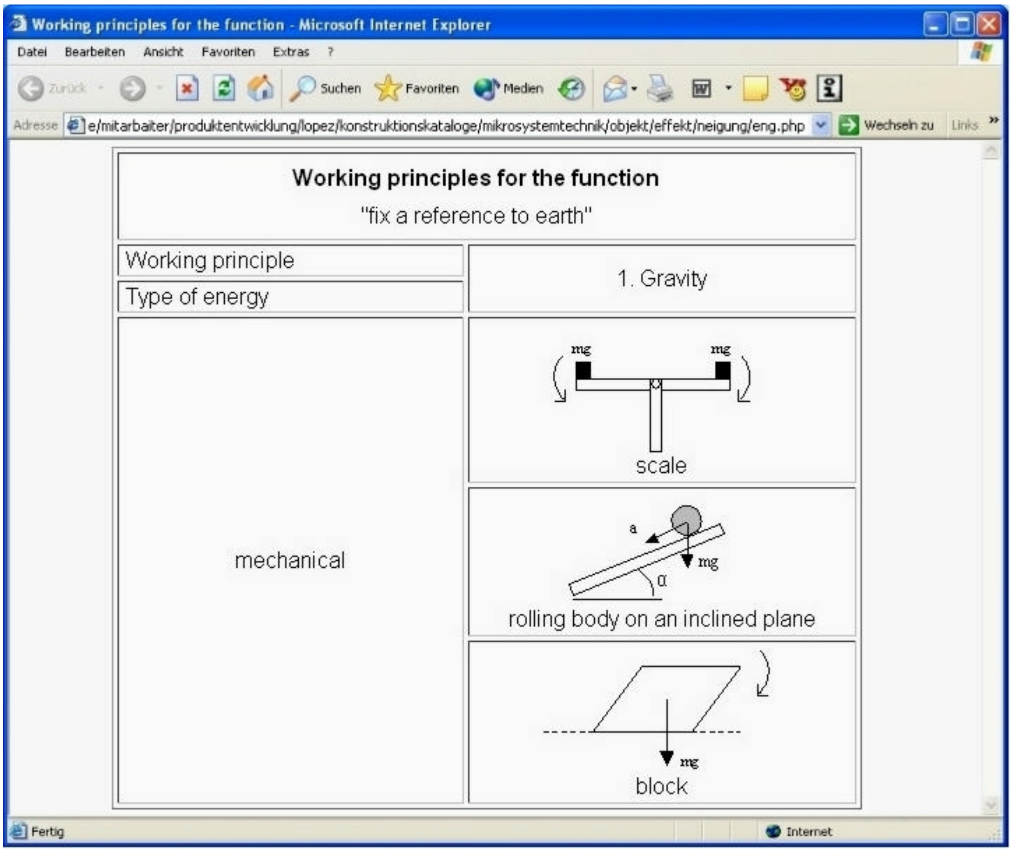


Figure 5. Hypermedia design catalogues – Mechanical working principles

The hypermedia design catalogues will be integrated into the improved design and development process for MEMS [7]. A test is planned to prove if they are helpful to:

- support the teaching of methods for product development
- transmit the systematic thinking to other application fields
- make designing/inventing learnable

4 Conclusions

This paper proposes a tool for transmitting multidisciplinary knowledge effectively. The integration of design catalogues methodology with information technologies could fulfil the requirements of microsystem engineering related to knowledge management, education and self-learning. The expansion of the proposed computer aided design catalogues for microsystems technology is currently underway.

Apart from purely objective data and suggested solutions, systematic links to examples of calculations, solution methods and design procedures could be added. These are valuable knowledge sources for students and professors that may help by keeping equilibrium between theory, skills and methods. Furthermore, it is essential for the learner to get the information as he needs it, e.g. when he is ready to assimilate it. With hypermedia design catalogues, he is able to try out different strategies in interaction with the computer system, in order to learn.

The independence of computer aided design catalogues regarding disciplines or companies may offer designers with no microsystem engineering curricula a tool that facilitates the understanding between engineering fields. Consequently, support by integrating effective interdisciplinary project teams could be achieved. Additionally, catalogues provide microsystems industry with a knowledge-management strategy by means of retrieval of known solutions and recording of new knowledge. This can promote a successful utilisation of expertise and creativity as production factors.

Basing this tool on an active-server would allow an interactive distribution of knowledge, turning the system into a powerful educational tool for online self-study and online training. Knowledge anywhere and anytime could diminish the pressure of project deadlines.

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