A SPECIFIC DESIGN METHODOLOGY FOR MICRO-ELECTRO-MECHANICAL-SYSTEMS TO SUPPORT LIFELONG LEARNING

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Abstract

The development of high quality MEMS products requires experts of diverse disciplines with actual knowledge. Experts have learned a larger amount of factual and conceptual knowledge enabling them to solve complex problems faster and more effective than novices do. Gaining and retaining expertise in a continuously developing field like MEMS technology is not possible without lifelong learning and should therefore be supported by adequate development procedures and methods to keep up with actual knowledge in involved disciplines.

This paper describes the characteristics of MEMS design and deduces demanded support of designers to achieve expertise in MEMS design. The suggested solution incorporates a new developed interdisciplinary design methodology and appropriate methods for MEMS design and was verified by implementation in divers MEMS design projects.

Keywords: Methodology, Micro-Electro-Mechanical-Systems, design process, lifelong learning

1 Introduction

Right from the beginning few decades ago MEMS (Micro-Electro-Mechanical-Systems) technology was regarded as a worldwide key technology for the 21st century with enormous potential and high rates of growth [1].

MEMS products are used in various fields, e. g. in automation, automotive or bio-medical industry, to enhance conventional applications or to open new areas of technology. MEMS technology integrates several domains, e. g. micromechanics, microelectronics or microoptics, in small package dimensions and therefore demands interdisciplinary cooperation of experts of diverse disciplines.

The field of MEMS developed by adapting microelectronic manufacturing technologies and is still immature [2]. Materials and manufacturing technologies are continuously improving. The development of MEMS asks domain experts to acquire both technological and design process knowledge to become MEMS experts. Furthermore they have to keep up with actual technological changes much more than in traditional disciplines. This requires lifelong learning far beyond continuing training in other disciplines to keep an actual level of knowledge, because designers have to observe their own and neighbouring domains throughout their professional life. The use of schemes, e. g. describing the design process, supports this process [3].

2 Expertise in MEMS design

2.1 Expertise in general

Understanding expertise, its prerequisites and success factors is important to obtain knowledge about the nature of general problem solving and to support designers in solving specific problems. The differences between novices and experts in solving problems were originally investigated in the 19th century in the area of solving well defined problems like chess playing [3].

A well defined problem is characterised by an initial state, a target state and a set of tools guiding through obstacles inhibiting the direct way from the problem to its solution [3], [4], [5], Figure 1. Novices usually spend more time following a trial and error pattern, experts trace less complicated paths to the solution using their experience.

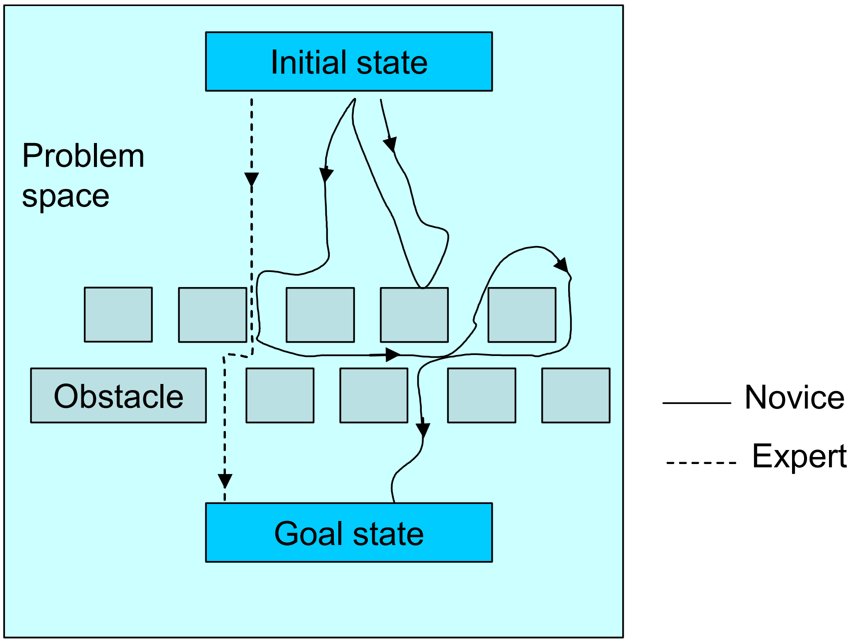

Figure 1. Problem solving

An extensive research study about expertise in the design area was carried out by Ahmed [6] to understand the behaviour of novices and experts approaching design tasks.

The definition of 'novice' and 'expert' differs between different research studies. Ahmed distinguishes by practical experience that emphasises the expert from the novice just accessing theoretical knowledge [6].

The approach to problem solving differs significantly between novices and experts.

Novices tend to reason backwards [3], [7], engage in less metacognition and retrieve any relevant source of information including folk theories that lead to invalid solutions [3]. Novice designers must first be supplied with the questions to guide them to relevant information [8] to prevent them from using trial and error patterns instead of particular design strategies [9]. Novice designers often evaluate in the end after generating solutions and implementing them, Figure 2, due to a lack of experience and knowledge.

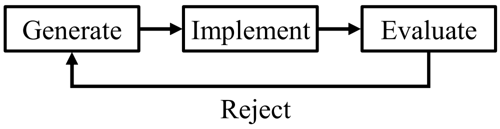

Figure 2. Novice Designers´ Pattern [9]

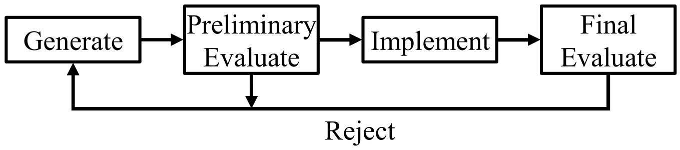

Figure 3. Experienced Designers´ Pattern [9]

Experts have learned a larger amount of factual and conceptual knowledge and organised it in a large number of patterns that serve as an index guiding them to the interpretation and finally to the solution of a problem [3], [6], [10]. This kind of knowledge includes schemata that help to find an appropriate way of problem solving and add crucial pieces of information [10]. Their greater degree of metacognitive control makes experts planning their solution strategy in order to simplify the problem to basic qualitative elements before using their knowledge schemes to find a solution [3]. Experts usually evaluate their decisions prior to implementation and avoid the trial and error pattern used by novices, Figure 3. Acquiring expertise through understanding a domain, discovering the best solution methods and practising them takes a minimum of 10 years of experience [3].

Factual and conceptual knowledge enables experts to solve complex problems faster and more effective than novices do [10]. Thus developing support methods for novice designers means that they should be provided with design strategies as well as knowledge and information [9], Figure 4.

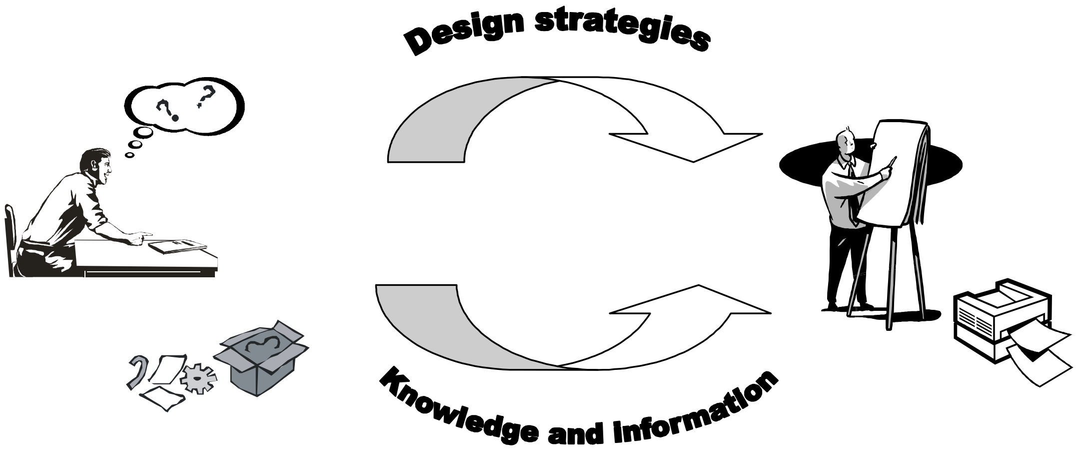

Figure 4. Support of novice designers

Knowledge and skills are situated and bound in a particular context [11], thus the particular demands of MEMS designers depend on the characteristics of MEMS design.

2.2 Characteristics of MEMS design

Methodological support for MEMS designers must consider the particularities of MEMS products, their application fields, manufacturing processes and resulting requirements on the design process. This demands an comprehensive survey of MEMS technologies and the analysis of the design approach in specific development projects. The analysis of the characteristics of MEMS design was based on a literature review verified by interviews with MEMS designers based on a questionnaire with over 90 topics.

The main focus was to find actual deficiencies of the design processes and promising approaches for improvement. The fundamental characteristics of the development of MEMS products are [2], [12], [13], [14]:

- a close interdependence between product, working principle, material and production technologies
- interaction of diverse disciplines integrated in a product, e. g. micromechanics, micro-optics, microelectronics, biology or chemistry
- a wide range of manufacturing technologies and processes, e. g. bulk micromechanics, surface micromachining, LIGA (from the initial letters of the German words for Lithography, Electroforming and Moulding) and MID (Moulded Interconnect Devices)
- a lack of standardisation
- continuously developing technologies and materials
- application dependent requirements

The analysis of characteristics of MEMS, their manufacturing process and their application fields show particular variations to other disciplines, e. g. mechanics. Requirements to a MEMS-specific design process are not fulfilled by processes of other disciplines [2], [14]. Structured development processes are not common practice in MEMS design due to the novelty of products and manufacturing technologies. Only few technologies are known, but not established [12], [13], [14]. Products are often based on brilliant ideas without systematic approach. Storage and exchange of knowledge for further developments are rare but essential [2], [6].

2.3 Expertise needs in MEMS design

Interdisciplinary design of MEMS differs from procedures in other domains and demands a common view on process and product as well as cross-functional knowledge [2], [14]. Furthermore support of the early stages of design, namely conceptual design, is important to improve MEMS products and reduce their costs.

MEMS design involves three aspects of learning:

- Novices usually have factual knowledge about at least one domain. They desire an extension of their factual knowledge to other domains and practical experience especially concerning design processes to become experts.
- Experts have factual and conceptual knowledge in their domain, but expertise in one field does not generalise to others. Thus they ask for knowledge in other domains and processes for interdisciplinary teamwork.
- Permanently changing knowledge due to technological advancement requires lifelong learning for everybody involved in MEMS design.

The first necessary step to distribute knowledge is to collect it from experts of different fields, the second step is to organise and to pass it to designers. Gaining expertise requires learning or apprenticeship [15], thus support of building up expertise incorporates a realistic presentation of the knowledge, procedures, and skills as well as opportunities to apply the knowledge and to practice the procedures and skills in a realistic context. In cognitive apprenticeship, which means the transfer of implicit knowledge from experts to instructors, providing appropriate scaffolds e. g. models of strategies to solve problems are a common tool to support novices in developing expertise [11]. Furthermore methodical support of novices in finding the right questions to ask, e. g. C-QuARK [6] may be useful.

Literature and questionnaire showed that an interdisciplinary and integrated MEMS design process would support designers. Development processes are often based on the approach of experienced designers. Thus information about design processes of various domains and peculiarities of MEMS must be collected, reviewed and utilised for an adequate MEMS design process.

Knowledge plays a major role in many steps of the MEMS development process and finding relevant information is one of the main problems of designers [16]. For example, drawing up a requirement list demands expanded knowledge of products, their manufacturing processes and their lifecycle. The selection of the working principle demands comprehensive knowledge of physical principles. The complexity of the interdependence between product, material and production technology requires actual knowledge that is often not available [2]. Thus it is not sufficient to supply knowledge without continuously updating it.

3 Supporting the Development Process

3.1 General approach

A suggestion for a development process model in MEMS design is illustrated in Figure 5.

It is based upon the V-Model applied in information technology and the VDI-guideline 2206 for mechatronics [17] and varied for the peculiarities of MEMS by consideration of experiences from analysed MEMS design projects.

This basic process model considers the complete product lifecycle from development via manufacturing, assembly and use to the recycling or reengineering of a product. It is important for designers to get knowledge of all theses phases to improve the fulfilment of requirements from different phases of the life cycle.

The development process starts with the generation of a system concept that is continued by a parallel development of the systems components in diverse domains and the manufacturing technology. This demands intensive exchange of interdisciplinary knowledge to achieve an optimised function of the system and avoid negative interrelations between components. The concluding system integration verifies the desired characteristics of the product. This general process must be broken down to operation steps and adapted to the demands of a company or an industry sector.

The methodology can guide novices without practical experience through development processes and support experts of partial disciplines in interdisciplinary projects.

Several stages of the development process can be enhanced by methodical support, especially concerning knowledge management. Knowledge of experts can be collected, reviewed, organised and provided for future applications. Development knowledge is often specific to company, application field or domain and therefore should be processed or adapted in particular companies or itemised for certain fields of application.

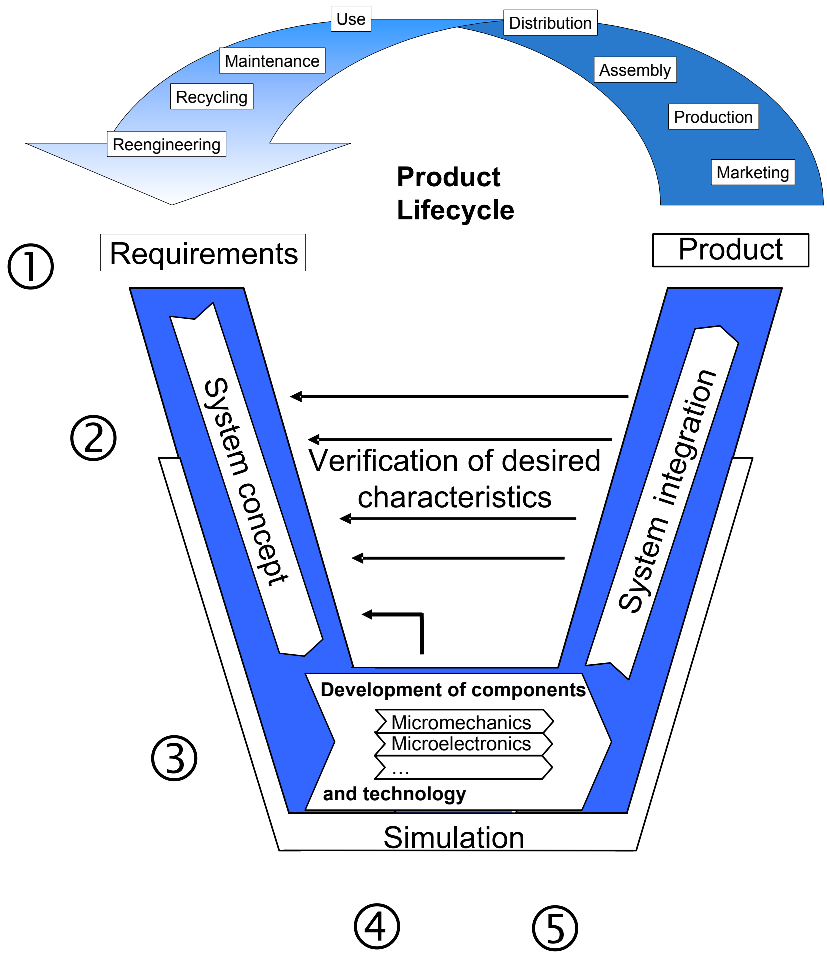

Figure 5. Methodology for the development of MEMS

Figure 5 contains five exemplary stages with methodical support concerning knowledge evolved from actual development projects:

- checklist for drawing up a requirement list ①
- catalogue of physical effects ②
- simulation with application of experience of former projects ③
- design catalogues ④
- design guidelines ⑤

All of these methods aim at collection and supply of relevant information and experience. Examples for a checklist for requirement lists and a catalogue of physical effects are desribed in the following paragraphs.

3.2 Checklist for drawing up a requirement list

A MEMS-specific checklist for the generation of a requirement list helps to consider all demands needed during the development process. Checklists are an approved method in other disciplines, e. g. mechanical engineering [5] and demand adoption to specific fields of application. Figure 6 shows a specific checklist for MEMS sensors.

Main headings	Examples
Measured value	Maximum value, minimum value, direction, frequency, speed, scanning rate, measuring accuracy, repetition accuracy, dissolution, accuracy
Connection to measured object	Attachment, arrangement, deformation, rigidity, distance, friction, interfaces, abrasion
Sensor characteristics	Weight, material, life span, size, height, width, length, diameter, number, space requirement, noise, heat development, electromagnetic emission, involved disciplines, extension
Operating conditions	Reliability, temperature, humidity, pressure, electromagnetic influences, light, mechanical vibrations, protection class, prescribed materials, maloperation
Electrical data	Voltage supply, kind of connection, power, efficiency, amperage, linearity, output signal, treatment of signals, signal storage, interfaces
Ergonomics	Type of operation, clearness of layout, display, aesthetics
Production	Preferred production method, means of production, achievable quality and tolerances, combination of production methods
Quality control	Possibilities of testing and measuring, application of special regulations and standards
Assembly	Assembly technologies, connection technologies, function integration, automated assembly
Transport	Shipping unit, special regulations
Maintenance	Service intervals, inspection, self test, exchange and repair, cleaning
Recycling and ecology	Reuse, reprocessing, material separability and recovery, waste disposal, storage, non polluting
Costs	Manufacturing costs, assembly costs, material costs, cost of tooling, investment and depreciation, retraction costs, quantities
Schedules	End date of development, project planning and control, resources, start of production, delivery date

Figure 6. Checklist for drawing up a requirement list

The checklist is divided in several MEMS-specific main headings with examples of aspects to be regarded. Checklists support novices in the preparation of requirement lists, store experts knowledge from earlier projects and encourage interdisciplinary cooperation. They require continuous revision and extension.

3.3 Catalogue of physical effects

A deep understanding of physical effects applied in MEMS technology is a precondition for the generation of a proper and working system concept. Divers development projects were used to gain physical effects applied in MEMS technology. They were arranged in a systematic order, categorised and stored in a catalogue of physical effects. Figure 7 partially illustrates the physical effect “capacitance” as an example. The displayed collection of geometric arrangements of capacitors elements with related formulas and variavbles is supplemented with a general description of the physical background, possible application fields and references for advanced information.

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Physical Effects	Capacitance	Electromagnetic
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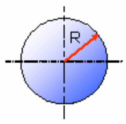
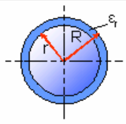
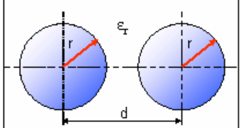
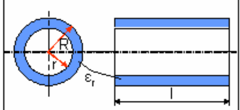
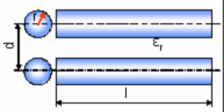
	Arrangement	Capacitance	Variables
Parallel plate arrangement		$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$	ε_r, A, d
Single sphere		$C = 4\pi \varepsilon_0 \varepsilon_r R$	ε_r, R
Concentric shells		$C = 4\pi \varepsilon_0 \varepsilon_r \frac{R \cdot r}{R - r}$	ε_r, r, R
Two spheres		$C = 2\pi \varepsilon_r \frac{d^3 + d^2 r - r^3}{d(d^2 - r^2)}$ für $d >> r$	ε_r, d, r
Coaxial capacitor		$C = 2\pi \varepsilon_r \frac{1}{\ln(R/r)}$	ε_r, r, R
Parallel Cables		$C = \pi \varepsilon_r \frac{1}{\ln(d/r)}$ für $d >> r$	ε_r, l, d, r

Figure 7. Catalogue of physical effects “Capacitance”

The catalogue supports novices and experts of non-electric domains in finding applicable effects, understanding the theoretical background, conceptualise the geometrical arrangement and design the resulting elements following the available variables. Experts can work out their knowledge and provide it for future developments.

4 Conclusion

Interdisciplinary design strategies as well as lifelong learning to keep up with a continuously developing technology are key competences in MEMS design for both novices and experts of diverse domains. This requires adequate design procedures and methods supporting knowledge management.

A MEMS development process model and two exemplary methods for MEMS knowledge management have been introduced. A suggested general development process model considers relevant aspects of the product lifecycle and supplies a guideline that can be adapted to specific development needs. A MEMS-specific checklist for drawing up a requirement list and a catalogue of physical effects support designers in storing, organising and reusing MEMS-specific knowledge.

The test and the evaluation of proposed MEMS design process, checklist and catalogue in MEMS development projects indicate acceptance and usability. Involved designers regarded them as a great benefit for their work. Nevertheless further use and evaluation in industry is necessary to optimise the usability and to enlarge the knowledge in different application fields.

MEMS technology is still continuously developing and therefore requires continuous verification and adaption of development processes and methods to ensure their practicability.

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