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FORMULATIONS OF PARADIGMS OF TECHNICAL INHERITANCE

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Abstract

The fourth industrial revolution is associated with changing production and design principles of machine parts. The purpose of this study is the development, elaboration and practical testing of an approach firstly proposed within the scope of the Collaborative Research Center (CRC) 653 "Gentelligent Components in Their Lifecycle". This approach is based on the adapted principles of evolution in nature: efficient development of the next generation of smart products based on the analysis of the life cycle data of the previous generations of the product and relevant information about their operation conditions. An analysis of contemporary trends in the technological community is provided and a brief overview given about existing approaches in optimization theory and technology using adapted mechanisms of nature. Basic determinations of the developed paradigm of Technical Inheritance are discussed. Using the example of within the scope of the CRC developed materials and methods the vision of applying the paradigm of technical inheritance is evaluated for the development and exploitation of smart components.

Keywords: New product development, Information management, Design methodology, Product lifecycle management

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1 INTRODUCTION

Design of components is a creative process that requires a comprehensive problem analysis. The main characteristics of this process are multi-variant solutions and the necessity to reconcile decisions based on general and specific requirements for constructions as well as relevant standards. Design can be assumed as a continuous chain of information processing where decisions at all design stages of components are required.
Here, one of the applied tasks is the accumulation of data about the development and usage of previous generations of products and an automated identification of relevant information about received loads and technical states of components.

1.1 The fourth industrial revolution

Presently, we are witnesses of the swiftly increasing fourth industrial revolution (Bauernhansl, 2014). Its motive forces are methods and facilities to collect, maintain, exchange and analyse data. The real expiration and its control and optimization currently coupled through virtual IT based processes and tools (Halang, 2014). Exact and timely authentication and classification of relevant information on the basis of data about the life cycle of products will allow to provide a systematic and effective research and to increase the reliability of machines and constructions at any stage of their existence.
Featuring sensory properties, components can inform in real-time about operating loadings, temperatures, vibrations, premature wear at certain positions etc. In future, such smart systems will be placed on machines and machine-tools. Using materials or components with sensory properties, developers will be able to plan the production and the supply with repair parts better; they will obtain the possibility to detect whether at certain component positions problems occur and to apply necessary design changes in time.

1.2 Smart components and mechanisms

A cyber-physical system of production will change the traditional logic of production fundamentally, since every object will determine, which work must be executed for its production. Thus, one aim is the development of intelligent machine parts and tools with the ability to collect, store and transfer data. Here, within the framework of the Collaborative Research Center (CRC) 653 "Gentelligent Components in their Lifecycle" (Denkena, 2014), smart components with sensory properties are being developed.
By means of the materials and technologies developed within the CRC components are enabled to process information. Thus, these can measure, record, process and save information about loads and strains during their manufacturing or usage such as forces, accelerations or temperatures. The overall information is connected inherent to these components and can be accessed at any time. Thus, these components are characterized by inherent sensory properties as well as inherent information storage and communication. Since these components feature properties of both genetics and intelligence, these are named "gentelligent" according to biological terms.

1.3 The relationship with biological systems

Developing parts with both genetic and intelligent properties, principles of nature have to be taken into account. Like genes in genetics, gentelligent components carry life cycle information, e.g. about their manufacturing as well as general component information.
Thus, not only a physical integration of reproductive information inherent to the components is realized but also sensory and evaluative skills regarding the component load during the life cycle.
Here, inherent information recording and storage contributes to the further advancement of production technologies and the product development for production systems of the future.
Within the CRC the authors are involved in the Work Group Inheritance (Lachmayer, 2014) to study properties and conformities according to the law of development in nature within the context of an adaptation of biological processes and the applicability of biological mechanisms to the construction of concepts of smart components. One research aim is the creation of the paradigm of inheritance in technical systems. In the focus of research are the creation of a terminology, the description of information transfer processes, an analysis of inheritance and the elaboration of an evolutional process of development of smart components and machines with genetic and intelligent properties.

2 THE EVOLUTION IN TECHNOLOGY

In technical systems, the transition to new models and generations is caused by the necessity to correct identified shortcomings and defects in the current version, as well as contradictions that are usually associated with improved efficiency criteria and occur in the presence of necessary and sufficient external factors.

At the same time there is a certain logic to change the structure of the technical system, based on the principle to obtain the desired effect by minimal changes of the structure and hence comparatively small changes in the manufacturing technology.

Extensive research has been carried out to identify the patterns of the development of technologies (Eversheim, 2009; Kemp, 1999; Hughes, 1987). Although the first laws of technological development have been formulated in the nineteenth century and the first classes of laws of development of technical systems in the late 40's to early 60's of the twentieth century, a unified system of laws of engineering and technical systems has not yet been developed.

2.1 The laws of technical systems evolution

Known laws of the evolution of technical systems were formulated by G. Altshuller (1984) and his followers: the law of completeness of the parts of the system, transition from macro to micro level, law of increasing the degree of ideality of the system, the law of increasing the S-Field involvement (S-Curve Law), etc.

Another vision of the laws is formulated in (Sahal, 1981). This theory, expounded in this work, is oriented to the study of processes of revision of systems more than on the process to create new ideas. The basis of the system are not inventions, but a gradual development of engineering, which conforms to some system of rules and which needs to be studied to create high-quality technologies and products. The main problem of choosing the optimum technology is the problem of improving the characteristics of the final product by improving the production process.

2.2 Using the principles of biology in the technology

The idea of using the principles, properties, functions and structures of nature and the biological principles of inheritance and transmission of information in technical devices and systems is not new and is the base for several optimization algorithms. The most famous examples are the genetic (Goldberg, 1989) and evolutionary algorithms (Rechenberg, 1973). Both methods use adapted mechanisms of nature, a biologically based terminology and a population of potential solutions; both implement the principle of selection and transformation of the most adapted individuals. Genetic algorithms operate on vectors of binary numbers or real numbers; real coding evolutionary algorithms operate on vectors of real numbers. The differences lie in the organization of the selection process and the sequence of procedures of selection and recombination of genes that is changing as a result of the application of genetic operators.

Using the principles of biological evolution and molecular genetics, Wegner (1999) and Vajna (2004) developed in their work the "autogenetic design theory".

Studying the synthesis of biology and technology it is necessary to mention bionics (Nachtigall, 2010). On the basis of knowledge of biological systems bionics borrows perfect design schemes and mechanisms from nature providing flexibility and survival under difficult environment conditions as well as it promotes determination of optimal solutions of engineering problems (Nachtigall, 2005).

In another form the principles of inheritance found an application in object-oriented design and programming. Examples are class diagrams in UML (Booch, 2006) and block diagrams in SysML (Friedenthal, 2012).

3 THE BASE MECHANISMS OF THE TECHNICAL INHERITANCE

Evolutionary processes of technical systems cannot take as a basis uniquely natural biological mechanisms of transmission of hereditary information. However, drawing parallels between the evolution of technology and the doctrine of evolutionary processes in nature, it is interesting to pay attention to the possibility of inheritance of acquired characteristics in living organisms, and technical systems with their parameters and properties under the influence of the environment.

Among the objectives to adapt biological mechanisms to the product development process can be noted: goal-oriented intelligent product development; high capability level; short regeneration and development stages.

3.1 Basic concepts of modern genetics

Closely related to the process of biological evolution is a combination of heredity and genetic variability that may be interesting in adapting biological mechanisms for the development of technology. Heredity is a property of organisms to repeat in a number of generations complex features: external structure, physiology, chemical composition, the nature of metabolism, individual development, etc. (Storch, 2013).

Genetic variability is a phenomenon to opposite to heredity. It consists of a change of combinations of properties for the individuals of this species. The novel properties of organisms are the result of variability and due to heredity they are preserved in next generations.

Evolutionary theory is the foundation of modern biology. The foundation of modern evolutionary theory is the synthetic theory of evolution, which arose from the Darwinism and population genetics. One of the first representatives of the theory was R. Fischer (1958). Supporters of the synthetic theory of evolution recognize three factors: *mutation*, generating new variants of genes, *recombination*, creating new phenotypes and *selection*, determining the phenotypes corresponding to the environment.

On the above described mechanisms the evolutional algorithms of optimization are based (Bäck, 2000).

An important feature of current research is the fact that in modern biology inheritance of properties, including acquired, is not studied at the level of single individuals but at the population level. Thus, the study of the biological mechanisms of inheritance and their adaptation to the principles of evolutions of technical components and systems should take into account mechanisms of mutation, recombination and selection, as well as the study of components at the population level.

3.2 Gentelligent Components

As described, within the framework of the CRC 653 smart components are developed which possess genetic and intelligent properties. To the genetic properties relate:

- Inherent storage of component and production information;
- Technical reproduction of genetic functions of storage and inheritance;
- Heredity of component information to the following generation n+1.

Among the intelligent capabilities of components:

- Autonomous acquisition and evaluation of life cycle information;
- Communication within complete systems (parts, machines, installations);
- Learning aptitude, knowledge base;
- Autonomous decision making based on knowledge and logic.

As genetic information of a component can be constituted the basic information which is necessary to identify or reproduce components or which helps to interpret geometric descriptions or information about materials. This information is stored as static, unchangeable data in the component and may have been inherited from an older generation of the component. In addition, the component contains the information about its production, which can be expanded, for example, through quality information.

3.3 Technical Evolution

Technology is developed in close interdependency with the social development and the ecosphere, so that there is a significant interaction and enrichment of the laws of nature, technology and society. For example, the development of technology depends on the needs of society and affects the development of nature. Evolution is not a linear process. In general, the evolutionary process has more a tree-type than a linear structure. This is explained by the process of natural selection and survival of the fittest individuals in every habitat. Fig. 1. depicts our vision of cut of the evolutionary process in technology.

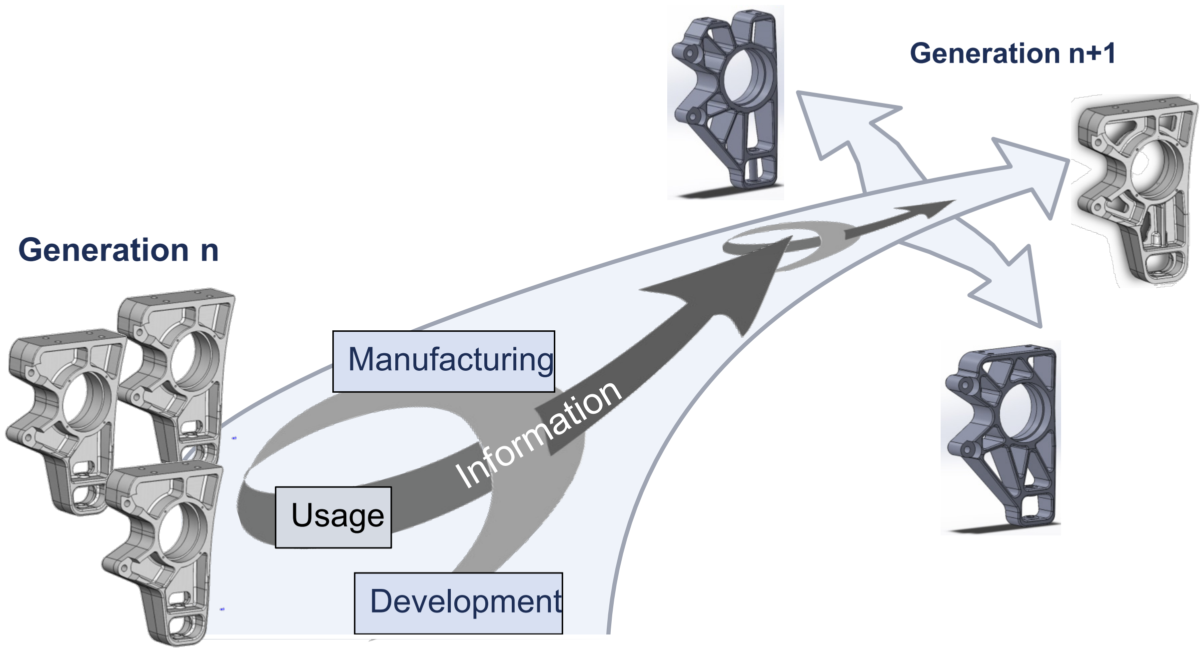

Figure 1. Information flow in the Technical Inheritance.

The process to create a new generation of components consists of three phases: development, manufacturing and usage. Information accumulated during the production and usage is applied in the development of a new generation. This takes into account the identified data collected through the operating features in different conditions. To obtain representative data it is necessary to analyze the data production and exploitation not only for a single component, but for the component population. As a result of the evolutionary process not only one new generation can be obtained, but somewhat different populations, each of which would be most suited to it‘s own pre-defined operating conditions. The Technical Evolution involves the accumulated experience of all previous generations into the development of the design of each new generation. Thus, an important part of the process of technical evolution is the correct analysis of the collected data and the allocation of relevant information for the development.

3.4 Important Terms

The above leads to the necessity to define terms of the process of technical evolution and descriptions of the terms. The results of the Work Group Inheritance in this direction are given in Table 1.

Table 1. Terminology of Technical Evolution

Term	Definition
Technical Evolution	Technical Evolution is a process of control, stepwise and continuous change of technical systems, products and processes as well as models with the aim to adapt to influences and requirements.
Individual	The individual is the smallest considered technical system, product, process or model in a population.
Generation	The generation is a group of individuals with the same level of development.
Population	The population consists of all generations of individuals of a technical system, product and process as well as a model at the current time.

Inheritance is the transfer of genetic information from one generation to the next. In nature inheritance provides the processes of doubling, distribution and integration of genetic material. Speaking of inheritance in technical systems should be, based on natural processes, adapt these to developments in the technology. It should be taken into account that biological processes are not designed for and do not transform unambiguously on the processes of evolution in technology. The collaborative results of adapting the definition of the mechanisms of technical inheritance to technical evolution are given in Table 2.

Table 2. The mechanisms of Technical Evolution

Term	Definition
Technical Inheritance	Technical Inheritance is the transfer of assembled and verified information from production and application to the next product generation.
Selection	Selection process based on multiple criteria a requirement profile.
Mutation	A process with targeted or non-targeted character to create variants with resulting modified properties.

4 THE PRACTICAL APPLICATION OF THE THEORETICAL FOUNDATIONS

One goal to realize a gentelligent production is the feedback of stored information from the gentelligent components into the product evolution and production evolution. For example, loading data acquired by wheel carriers during driving shall be used for a further evolution of their shape in the following component generations.
During development, production and usage of products evolutionary principles are applied: information is inherited by the following generations and lifelong learning occurs.
The intelligence of gentelligent components is based on the technical capability to acquire, process and store information of the stages of production and usage such as forces, accelerations or temperatures.
Therefore, suited technologies are implemented into the closed cycle of gentelligent parts with the stages product design, manufacturing, usage and information feedback.
Furthermore, an improved signal analysis and signal transmission, enhanced storage capacities and increased component performances are investigated (s. Fig. 2).

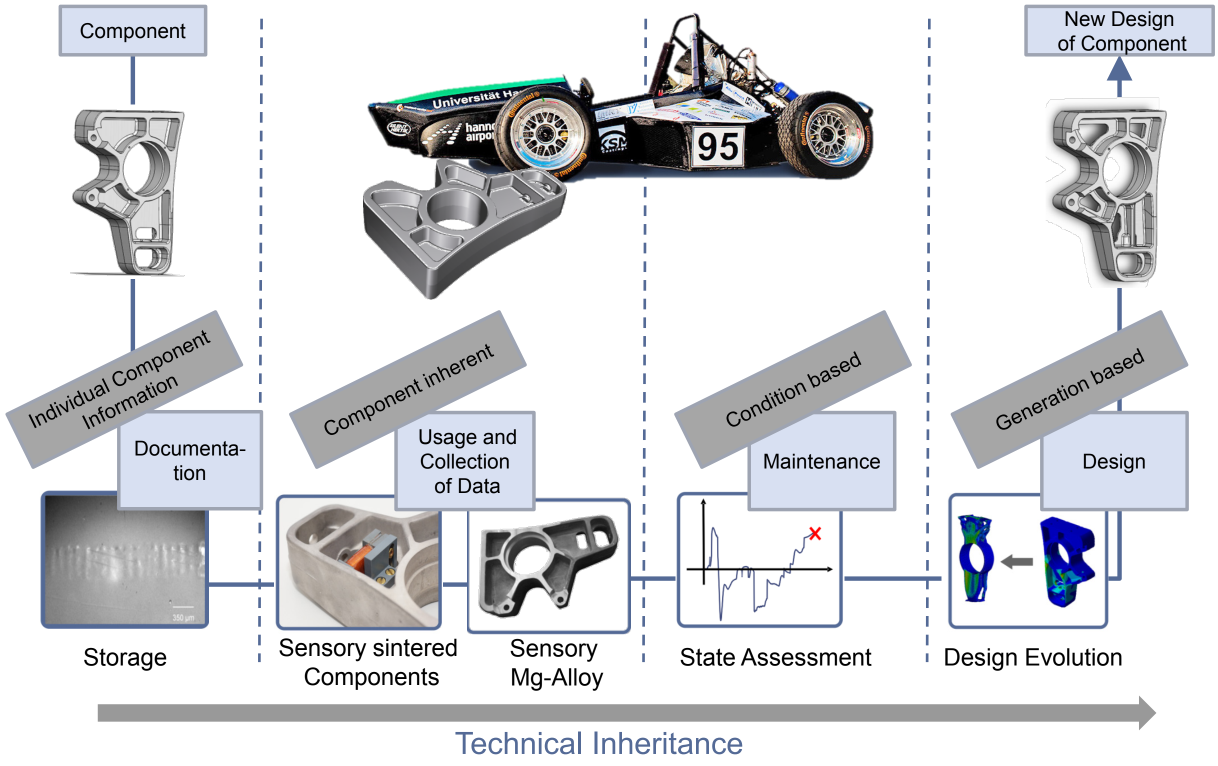

Figure 2. Working steps of the Usage and Development Phases of Gentelligent Components

By inherited reproductive information and suited evaluation capabilities regarding component loading during life cycle an evolutionary adaptation of the following generations according to the requirements is achieved.
Main aspect is the technical inheritance and the mechanisms of technical evolution. Here, genetic information is defined as the basically information to identify, reproduce or redesign components regarding geometry, material and external loadings.
By this information the external loadings during the life cycle, such as forces and temperatures, can be described with high precision. Loading information from the product life cycle is applied to optimize parts and components, to adapt these to operational conditions and to improve maintenance strategies.
It is a vision to transfer nature's evolutionary process to technical systems. Here, the product model and its parametrization represent the genotype, whereas the various generations of gentelligent products represent the phenotype of technical products in their environment.
In contrast to nature, only vital phenotypes which are in accordance to specified requirements shall be used. Starting from a first generation, target-oriented optimizations shall occur. Especially the producibility of the functional optimized components is of special interest. Here, unlike other works about evolutionary strategies and genetic algorithms during product development, the phenotypes are real parts in usage and not only various generations of models. The algorithmic design evolution to adapt components to modified operation conditions results in improved parts regarding the parent generation.

Methods and processes are part of a development environment of "Design evolution by algorithmic information feedback form the product life cycle", Fig. 3.

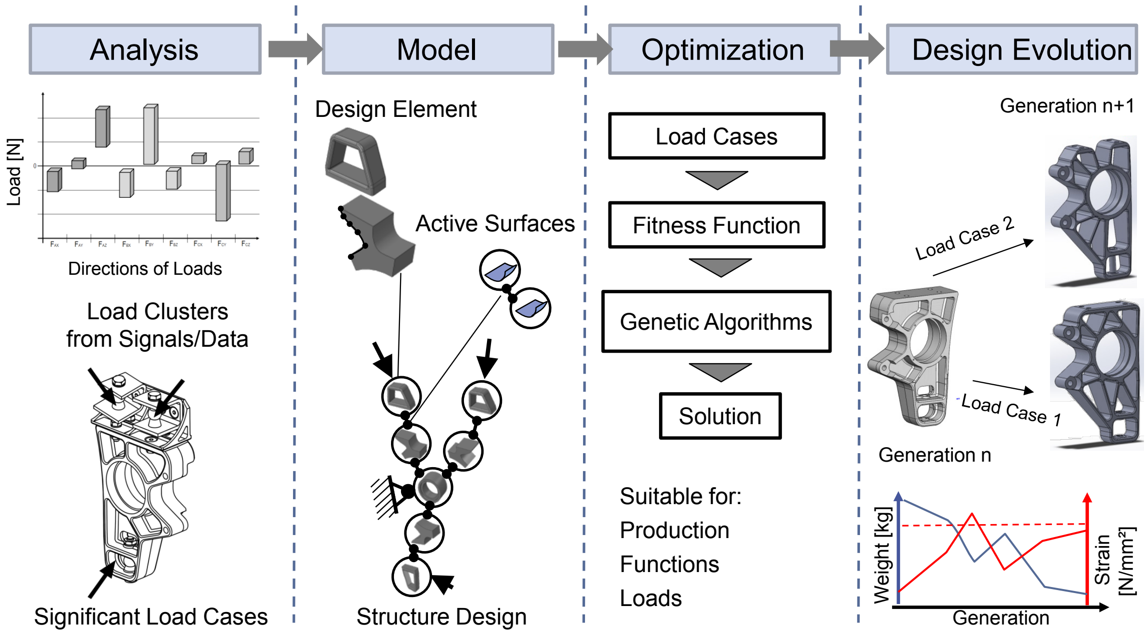

Figure 3. Design Evolution by algorithmized information feedback from the Product Life Cycle

Basic important aspects and advantages by the offered approach are accordingly to the work steps of technology (Fig. 2) the possibility of direct writing and read-out of individual information directly on the surface of the components, component's inherent load capture, state-based maintenance and optimized geometry of the component.

5 CONCLUSION AND FUTURE RESEARCH

Current trends in the development of smart systems are described as well as the basic theory of the evolution of technical systems; a brief analysis of the mechanisms of biological inheritance is given and formulations of the evolutionary approach towards the development of technical systems presented. Examples of the application of the developed approach and suited work steps to exchange information within the framework of the Technical Inheritance are described.

The main results are the concepts and definitions of the process of technical evolution. Inheritance in technical systems is based on the ideas to use natural processes by adapting these for a technological development. A first version of a common terminology and description of the Technical Inheritance processes based on biological principles of information transfer has been established. Technology-based mechanisms of Technical Inheritance were explored using a demonstrator.

Future investigations include a verification of the terminology and description of information transfer processes within the scope of mechanism of technical inheritance.

Furthermore, of importance are questions of succession of generations of products in technical systems, relevance and optimization of the transmission of information through a series of generations and presentation of genetic information in technical systems.

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