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Technical inheritance: A concept to adapt the evolution of nature to product engineering

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Abstract

Nowadays the technological progress of technical products occurs according to the laws of natural selection: new technologies are replacing old ones, winners of the competition are those products that best meet the expectations of society and the requirements of the market. Therefore, using, adapting and modeling of the basic laws of the theory of biological evolution in order to study the evolutionary processes in technical systems are already many years a popular area of research. Modern technical solutions combine the ability to store and transmit information on their technical specifications and accumulated changes from generation to generation. The main research area of the Collaborative Research Centre (CRC) 653 "Gentelligent Components in Their Lifecycle" is the innovative development of smart products in which the genetic and intellectual dimensions are a combination that enables to use the accumulated product life cycle information for the development of subsequent generations adapted to their environment. One of the central questions of the evolution of technical products is how to consider inheritance and the transfer of information. Based on evolutionary mechanisms the definition of technical inheritance as a transfer of assembled and verified information from production and application to the next product generation has been composed. The authors employed the analysis of existing evolutionary theories in biology, evolutionary laws of technical systems and their adaptation as well as the redefining of gentelligent smart products.

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Keywords: Technical inheritance; information, technical evolution

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1. Introduction

Since the Age of Enlightenment science has evolved in accordance with the Bacon's idea: to learn the laws of nature and put it at the service of mankind. This approach has led to the emergence of industrial solutions in the nineteenth century. People lived in the world of industrial optimism, at least, to the middle of the twentieth century. However in the second half of the twentieth century the science and the industry more and more actively used the ideas based on natural mechanisms. It is genetics, information theory, evolutionary strategy, psychology and sociology. In recent decades, humanity makes extensive use of the first practical results. Throughout world history this is just the beginning, but now the approach to industrial development is radically different from the existing one only two generations ago.

According to the biological principles the objective in the CRC 653 is the technical development of higher valued gentelligent components which are equipped with genetic and intelligent properties. Thus a physical integration of the reproductive information as well as sensoric abilities with regard to the component's loads during their life cycle shall be realized in the component inherently. The inherent information acquisition and storage makes an important contribution for the advancement of the production technology and the product development for use in production-technical systems of the future.

1.1. From "embedded systems" to "inherent systems"

The applicability and integration of embedded systems in engineering nowadays is limited, especially for simple components. As depicted in Fig. 1 on the left, the sensors, converters and storages are not embedded but attached.

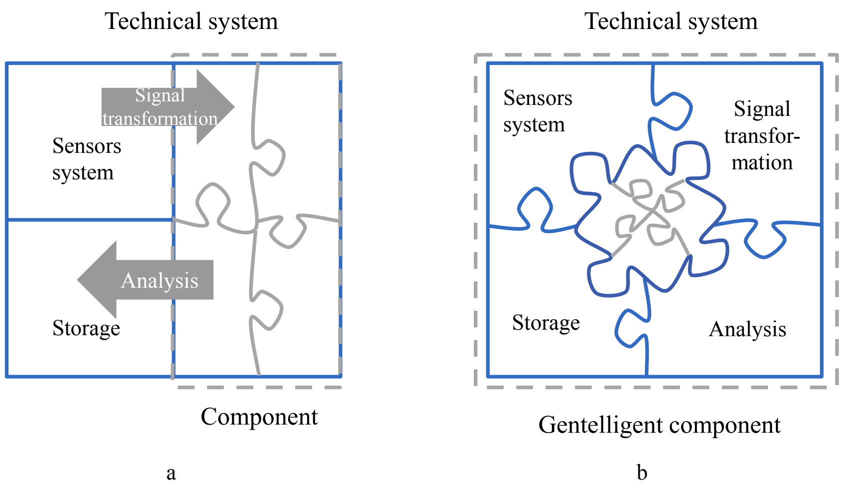

Fig. 1. (a) Embedded System: sensors, converters and storages are not embedded but attached; (b) Inherent System: abolition of the separation of component and related information through the development of gentelligent components.

By the within the CRC developed materials, technologies and processes, the gentelligent components feature abilities to load, store and to process information such as applied forces and temperatures during their production and usage. This complex information is inherently connected with the gentelligent component and retrievable any time. Thus, the gentelligent components are characterized by inherent sensory properties and the ability to inherent data storage and communication between itselves (Fig. 1, a).

2. Technical evolution

In technical systems that perform specific technical functions, transition to new models and generations is caused by need to eliminate revealed shortcomings, defects and contradictions and is usually associated with improvement of an efficiency criteria and the occurrence of available necessary and sufficient external factors. Herewith there is a certain logic to change the structure of the technical system, based on the principle of getting the desired effect by minimum changes and regarding a minimizing of costs at modified manufacturing techniques. Any system, including any technologic, is developed by the laws described as early as in the works of G. Hegel [1]. Accordingly, the technique serves to man, and its character is dependent on external conditions, i.e. subject to the laws of nature. Among the works devoted to development of technology and determination of its laws the writings from M. Eyth [2], M. Schneider [3], F. Dessauer [4] and E. Kapp, who firstly entered the term "philosophy of technick" in work [5] should be noted.

Although the first laws of technical evolution were formulated in the nineteenth century, and the first classes of laws formed in the late 40th to early 60th years of the twentieth century, yet no common system of laws for technology and technical systems is available.

2.1. Laws of technical system evolution

The laws of technical evolution [6] describe an idealized process of a technical system development and can be classified for example into three categories: static, kinematic and dynamic laws. The laws can be applied regarding two different aspects: the laws of the organization that determine the systems‘ viability and the laws of evolution, determining an elaboration of a technical system. Competition winners are those systems that best meet the requirements of the society. Usually these are efficiency, reduced consumption of resources and waste. As long as the most various technical systems face approximately the same problems the methods of their decision are generally stereotypic.

The most known laws of technical system evolution were formulated by G. Altschuller [7] and his followers: the law of completeness of the parts of the system, which provides the minimal functionality; the law of transition of working parts of system from macro to micro level; the law of increasing the degree of ideality of the system; the law of transition of quantitative changes into qualitative or the law of increasing the S-Field involvement (S-Curve Law), etc.

2.2. The Law of increasing the S-field involvement

In technical systems with identical functions transformation from generation to generation is motivated by the elimination of the revealed main defects regarding the improvement of development criteria. These transformations occur in the presence of the required scientific and technological level and the socio-economic suitability by following the most probable ways of the exhaustion of design possibilities [7]:

- system parameters are improved towards the global extremum by the invariable physical principle and the technical solution;
- after the capacity exhaustion a transformation to more efficient technical solutions takes place, after which the development again goes on a loop. The cycles are repeated until reaching the global extremum of the technical principle.

Thus the evolution of multiple systems can be depicted by a logistic curve that shows its change in time the path of development. There are three typical stages:

- **Stage I**: "childhood". This is usually sufficient long. At this point, the system design is finalized, the prototype is manufactured and the system is prepared for mass production.
- **Stage II**: "flowering". The system rapidly improves and becomes more powerful and productive. The product is available commercially, its quality is improving and demands are growing.

- **Stage III**: "old age". By time an improvement of the system becomes more and more difficult. Despite the efforts of designers, the development of the system cannot fulfill the increasing needs or requirements. Finally, all resources are limited. When trying to artificially increase the quantity of systems or developments, leaving the old principle, the system will be itself in conflict with its environment and human beings and may be starting to bring more harm than use. Therefore, at the development of system there might be a **stage IV**: deterioration of certain parameters of system. Fig. 2. depicts a typical S-Curve for a system or technology.

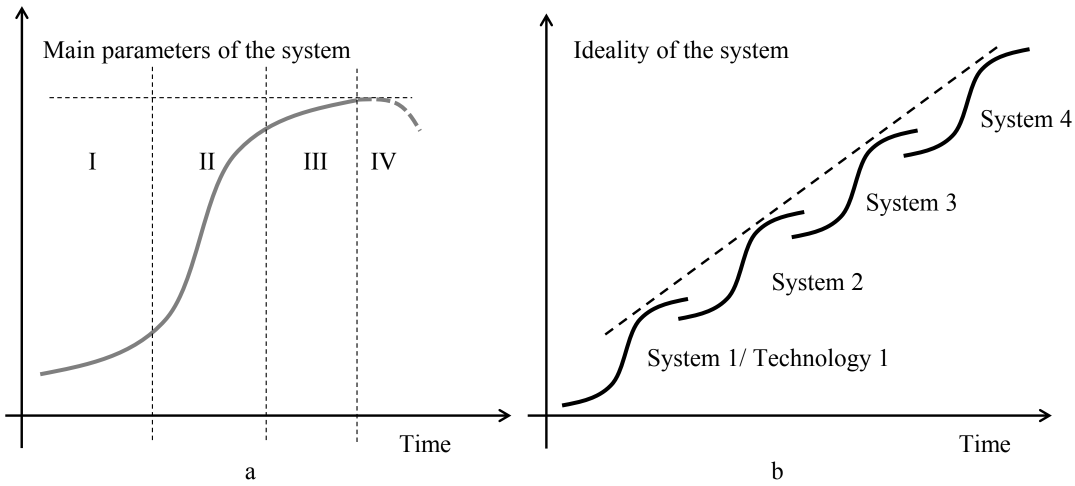

Fig. 2. S-Curve of systems life cycle: (a) typical curve of system growth; (b) spasmodic development of system.

The termination of a system's growth does not result in a termination in this area. Newer and better systems appear and development is taken to a higher level. This process is depicted in Fig. 2 on the right showing the transition of quantity into quality. Quantitative changes in the system are continuously. Qualitative changes occur in steps due to reaching certain limit of the system. New quality accelerates growth rates. Thus the technical system passes some stages of the development. The general industrial progress can be approximated by using the tangent to the curve, the so-called envelope curve.

It is interesting that for the first time S-curves were described in biology in 1845 by P.F. Verhulst in the study of yeast fungus colonies. By analogy, it can be concluded that each system has its own critical point to start its development and favorable combinations of external conditions. Practical examples to demonstrate the laws of technical systems evolving are given e.g. in [8, 9].

2.3. Sahal laws

Another vision of the type of laws is formulated by D. Sahal [10]. This theory is more focused on studying processes of system improvement than on processes to create new ideas. The development of systems is not based on invention but gradual engineering. Gradual engineering development happens according to regularities. It needs to be studied to create good technologies and products.

This approach assumes to search simple generalizations which represent the logical structure and easily recognizable abstractions constructed on the basis of empirical data. A search of simple functional ratios is applied to determine the laws. Such laws are usually simple and contain relatively few arbitrary parameters. The usefulness of the law is more dependent from a class of cases which it describes than from the accuracy of the predictions in each case.

The main challenge in choosing the right technology is improving the characteristics of the end product by improving the manufacturing process. Furthermore, the concept of a "progress function", that is regarding an increase of productivity of system due to professional development, experience accumulation, improvement of the equipment, and a design, etc. is proposed.

Technological changes often take the form of a series of small innovations that result in little individual cumulative effect. But in certain cases the system reaches typical "crisis points". After that the system development changes radically.

3. Evolution in nature

The biology became a major direction of development of evolutionary theories. Technology development takes place in close interaction with society and the ecosphere. Consequently, there is significant penetration and mutual enrichment laws of nature, technology and society. For example, development of technology depends on requirements of society and makes influences of nature development.

3.1. Lamarck's theory

In 1809 Lamarck created the first theory of biological evolution [11]. The theory of evolution suggests that organisms are changing due to the impact of the natural environment, thus acquiring different properties. The theory is based on two allegations: the inheritance of acquired properties and the inner, inherent commitment of all living creatures to perfection. The first statement explains why organisms are well adapted to living conditions; the second explains the complexity of organisms and the emergence of new organs and tissues.

3.2. Theory of Darwin

In 1859 the evolutionary theory of Charles Darwin's was created [12]. He has put forward the principle of natural selection as a basis of evolution. The model of inheritance of the acquired characteristics created by Darwin, named the theory of a pangenesis, features some similarities compared to the theory of Lamarck. The theory of pangenesis partially explains the mechanism of inheritance of the acquired characteristics.

In the 20th century many new ideas appeared in the field of evolution, for example, the theory of molecular evolution from M. Kimura, the selfish gene idea of from R. Dawkins or the homogenesis theory from L. Berg, etc. Interestingly, in the world of technology the law of the progressive evolution is analogous to the law of natural selection proposed by Darwin. This answers the question, why the transformation from a previous generation of the technical object to the next improves the generation; furthermore, it explains under which conditions, when and which structural changes occur in the transition from one generation to the next.

3.3. Modern evolutionary synthesis and Neo-Darwinism

The theory of Darwin supported in the first half of the 20th with genetic researches, turned into the Modern Evolutionary Synthesis Theory. R. Fischer [13] was one of the first representatives of the theory. Supporters of the synthetic theory recognize participation in evolution of three factors: the mutations for generating new options of genes, the recombinations for creating new phenotypes and selections to defining a conforming between phenotypes and environment. On the described in theory mechanisms are based, for example, evolutionary optimization algorithms [14].

At the same time, the concept of neodarwinism, created by A. Weismann [15], rejects the possibility of inheritance of the acquired characteristics and postulates the development of living organisms from the point of view of the Darwin theory of natural selection.

3.4. Epigenetics

The genetic laws determined first by G. Mendel assume regularities of mechanisms of heredity of living organisms. One of the modern directions of these genetic researches which are of interest from the point of view of inheritance of the acquired characteristics is epigenetic [16, 17]. This term was proposed in 1947 by C. Waddington.

According to epigenetic research there are some ways to acquire characteristics by inheritance nowadays. These methods are not associated with changes in DNA sequences, therefore such heredity is called "epigenetic".

Evolutionary process development of technical systems cannot **unambiguously** use natural biological mechanisms of inheritance as a basis. However, drawing parallels between the evolution of technic and the evolutionary processes in nature, it is interesting to pay attention to the inheritance of the acquired characteristics in living organisms and the inheritance of parameters and properties in technical systems under the influence of their environment.

4. A Concept of Technical Inheritance

The intelligence of gentelligent components is based on its technical abilities to capture, to process and to store information during production and usage as applied forces and temperatures. The CRC 653 provides the scientific background to create such gentelligent components.

4.1. Technical systems are using the principle of nature

Based on genetics a GI component is like a gene featuring the functionality to carry information about the individual component and its manufacturing over the complete life cycle. Thus, its own base information is stored inherently in the component, so that a physical separation of the component and the related information no longer exists. Since this information remains unchanged throughout the entire life cycle, it is called as "static". The intelligence of the GI component is characterized by automatically collecting "dynamic" information that is available during usage and may be constantly transmitted to an overall system, which analyzes and assesses the data and has the possibility to identify some physical defects itself and autonomously solving problems.

The system uses the applied data collection for learning phases. It stores the identified correlations and optimization suggestions for further improvements, and thus accumulates a knowledge base that can be applied to current problems. The GI component is active, adaptive and communicates with components and facilities in the overall system. The collection and inherent storage of information about component loads, environmental influences etc. occurs during the whole life cycle and results in documented a component-specific load history, which can be used in addition to the knowledge base to estimate the remaining service life and to improve the component characteristics in the context of maintenance measures or for the next generation.

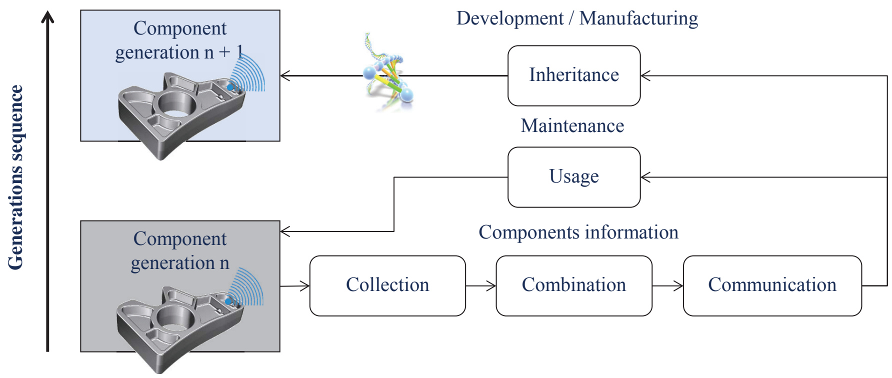

Fig. 3. Technical inheritance in life cycle of a component.

In biology genetics have evolved over millions of years thus providing a system that is applicable according to our view regarding automation of product and process planning though technical systems require faster adaptations for engineering. Here, the combination of genetics and accumulated knowledge can be a successful attempt.

Therefore, we store the information from the usage phase in the component inherently with the goal to inherit it to new generations as well as an adaptive improvement of manufacturing and product development processes (Fig. 3).

4.2. Evolutionary adaptation of the component and component generations

Through inheritance of reproductive information as well as perception and assessment abilities regarding the components loads in the life cycle an evolutionary adaptation of the next component generations according to the actual requirements takes place.

The main focus is the aspect of technical inheritance, i.e. a transfer of assembled and verified information from production and application to the next product generation. Genetic information of a component can be information about identification, reproduction or re-design of the component such as geometry, material and load information (Fig. 4). This information gives for the different phases of the life cycle a very exact picture about loads such as mechanical or thermal ones. Load information from the product life cycle is used to optimize components and assemblies, to adapt these to various application conditions as well as to improve the servicing strategy.

The vision is to transfer the evolutionary process from nature to technical systems. In this case the product-representing models and its parameterization correspond to the genotype, while the different generations of the gentelligent components form the phenotype (the respective technical product) in its environment. In contrast to nature is has to be ensured that only viable, the requirements meeting phenotype definition are used.

Starting from the first generation targeted optimisation should take place where the manufacturability of the function-optimized components and assemblies must be ensured in particular. In contrast to other works about evolution strategies and genetic algorithms in the development process in the present case the phenotypes are real operating parts, and not just various generations of models. The algorithmic design evolution for the adaptation of the components to changed operating conditions leads to a better achievement for the new components compared with the parts of the parental generation. Methods and processes are presented in the form of a development environment for design evolution by algorithmic information feedback from the product life cycle. Thus, the process of forward development happens in relative repeatability, as though on the passable steps. Each repetition happens at a higher level to apply new elements, materials, technologies, etc. Development occurs as a spiral.

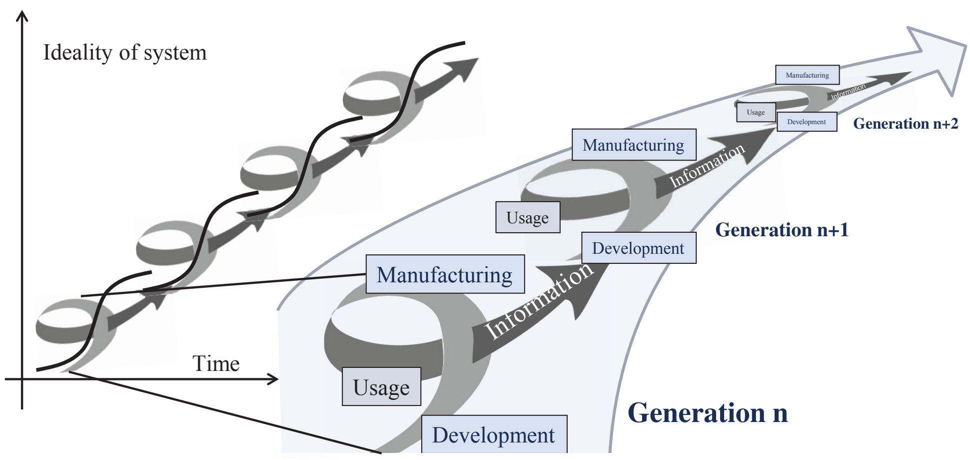

Fig. 4. Technical inheritance as a transfer of assembled and verified information.

Evolutionary product development processes are determined by the environment and, analogue to biological processes, the implementation of selection amongst properties or characteristics and populations. Technical population evolves in accordance with the rules of selection and in accordance with the target function that considers the environment. The result of the technical evolution can be regarded as a functional optimization task, described by a suited mathematical language and implemented as virtual or physical prototypes.

4.3. Evaluation and feedback of inherent component information

The intelligence of the gentelligent component created by its technical ability to capture and process, information such as applied forces and temperatures in the production and usage phases. The CRC 653 provides the scientific basis to manufacture these gentelligent components [18].

For this purpose the technologies of the subprojects are integrated in the closed circulation of gentelligent components with the phases of the product development, production, usage and return of information. In the project areas ongoing developments regarding the signal analysis and signal transference, storage capacity as well as transferability and efficiency increase are carried out (Fig. 5).

In the subproject E2 magnetic magnesium alloys with sensory properties are developed which enable an online measurement of the mechanical force acting on the component. The main objective is the material inherent inheritance of information, that is identification of conditions at which a gentelligent component from a sensory magnesium alloy during its usage phase has been overloaded. To transfer the results from the laboratory experiments to realistic cases, the eddy current measurement technique is adapted by subproject S3 to the geometry of a wheel carrier. First, the components are unloaded and measured in the critical areas using the eddy current method. Afterwards the results of the local harmonic measurements in the magnetic ground state are written encoded into the material. The by different load cases achieved overloading results in a permanent change of the harmonic measuring values in the deformed component area measurable after the load phase. From the measuring data local deformations and the degree of the plastic deformation are determined. This information is transmitted to the subproject N4 which carries out a geometry optimization of the tested component based on the real measured overload data by using a genetic algorithm.

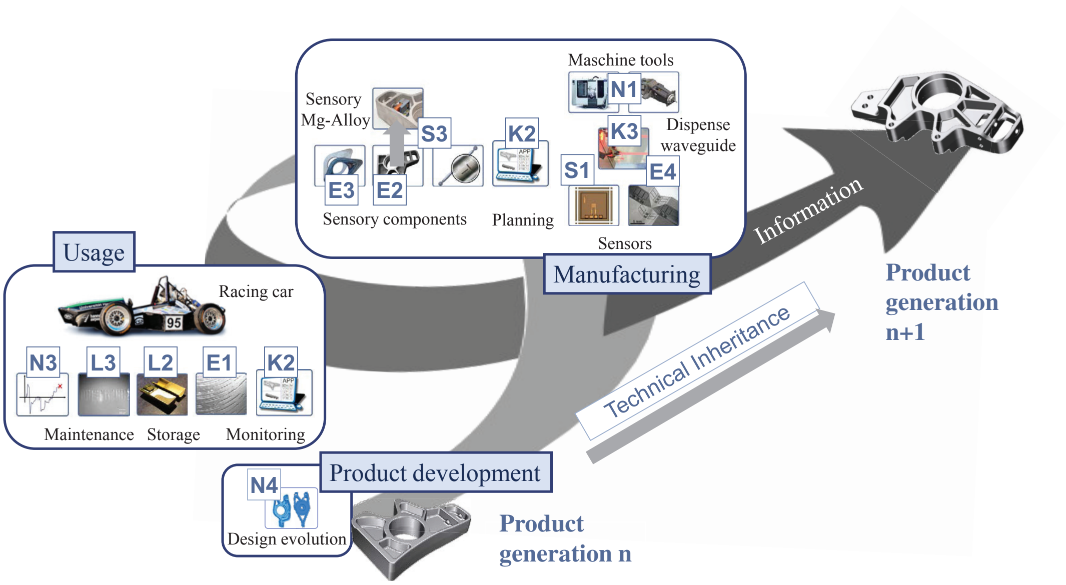

Fig. 5. The subprojects of the CRC on the phases: Product development, manufacturing, usage.

The gained knowledge is used to develop machine tool systems, which have considerable advantages in terms of accuracy, flexibility and data consistency over conventional systems. A machine-integrated sensor system from the CRC projects area K in the machine tool enables the reconstruction of the tool wear by signal processing and can be used for a state-based tool application management. In the CRC projects area N a gentelligent tool carriage was developed, integrated into a tool machine together with the gentelligent instep system and used to observe the machine state at a milling process.

5. Conclusion

Inheritance is the transfer of genetic information from one generation of an organism to another. In nature processes of doubling, association and distribution of genetic material occur. Inheritance in technical systems is based on the ideas of those natural processes by adapting these for a technological development.

According to the biological principles of transfer of the hereditary information technical inheritance has been composed. At first a common terminology and description of the technical inheritance processes based on the biological principles of information transfer has been established. Using the example of a smart product the steps of this new approach of product engineering are presented in detail.

Using the example of CRC demonstrators the application potentials of gentelligent components and systems in development, production and usage phases has been presented. The focus of the demonstrator for the gentelligent components production is the usage of a gentelligent machine by cooperation of the subprojects E1, E2, E4, K1, K2, L2, N1 and S1. By means of the production of a wheel carrier the manufacturing process using the example of milling was monitored by gentelligent machine components and, finally, the "genetic information" was structured and placed onto the surface. The wheel carrier is the connector for the second demonstrator, the gentelligent chassis, which due to the close cooperation of subprojects E2, E3, E4, S1, S2, S3, L2, L3, N3 and N4 had been developed. Using the example of wheel carrier a gentelligent system was realized. Thus, after successful integration into the racing cars of the university group Formula Student loads could be recorded and stored. After driving this data can be read, processed and an initial indication of the potential remaining life time approximated. Based on preliminary investigations a design evolution of the wheel carrier could be carried out. Together with the CRC workgroup "Inheritance" a technology-based mechanism of technical inheritance was investigated on the demonstrators. For the integration of the approaches in the context of an gentelligent production and to investigate the technological potential for industrial usage a "Gentelligent Product" will be manufactured in future. The main directions of practical use of the described approach are connected with the creation of a concrete class of technical systems within the methodology of a choice of competitive decisions, system methodology of design activity and development of techniques of posterior studying of technical evolution. In addition, the specified regularities of technical development allow specific tasks of predicting and improving structures of technical systems.

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References

[1] Hegel G. Wissenschaft der Logik. Edition Holzinger. Taschenbuch; 2013.
[2] Eyth M. Poesie und Technik. Berlin, 1908.
[3] Schneider M. Über Technik, technische Denken und technische Wirkungen. Nürnberg; 1912.
[4] Dessauer F. Philosophie der Technik. Bohn; 1927.
[5] Kapp E. Grundlinien einer Philosophie der Technik. Braunschweig, 1877.
[6] Eversheim W. Innovation Management for Technical Products. Springer-Verlag Berlin Heidelberg; 2009.
[7] Altschuller G. Creativity as an Exact Science. Crc Pr Inc; 1984.
[8] Kemp R, Mudler P, Reschke C.H. Evolutionary theorising of technological change and sustainable development. Rotterdam: Research Centre for Economic Polic. 1999.
[9] Thomas P. Hughes. The Evolution of Large Technological Systems. Cambridge: The MIT Press;1987. p. 51–82
[10] Sahal D. Patterns of Technological Innovation. Boston: Addison Wesley Longman Publishing; 1981.

[11] Honeywill R. Lamarck's Evolution: Two Centuries of Genius and Jealousy. Murdoch Books; 2008.
[12] Storch V. Evolutionsbiologie. Berlin: Springer Verlag; 2013.
[13] Fischer R. The genetical theorie of natural selection. New York: Dover Publications Inc; 1958.
[14] Bäck T, Fogel D.B, Michalewicz Z. Evolutionary Computation 2. Bristol: IOP Publishing Ltd; 2000.
[15] Weismann A. Essays uppon Heridity. Oxford: Clarendon Press; 1889.
[16] Kundu T. Epigenetics: development and disease. Berlin, Heidelberg: Springer Verlag; 2013.
[17] Cabej N. Epigenetic Principles of Evolution. Oxford: Elsevier; 2012.
[18] Denkena B, Mörke T, Krüger M, Schmidt J, Boujnah H, Meyer J, Gottwald P, Spitschan B, Winkens M. Development and first Applications of Gentelligent Components over their Life-Cycle. CIRP Journal of Manufacturing Science and Technology 2014;7(2):139-150.