NATURE-INSPIRED APPROACH FOR FUTURE COMPONENT GENERATIONS

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ABSTRACT

Nature-inspired applications will be found manifold in future manufacturing systems along the product development process and product lifecycle. Understanding biological principles and transferring the gained knowledge to man’s technologies or systems enables innovative product designs, new functionalities of components or improvement of current engineering solutions by means of nature-inspired algorithms. A novel approach is illustrated in the presented paper referring to nature-inspired component design. In the Collaborative Research Center (CRC) 653 “Gentelligent Components in Their Lifecycle” at the Leibniz Universität Hannover, a new generation of components with sensing capabilities and inherent data storage capability are currently developed. These new components will in the future enable self-inherent authentication, the perception of environmental information like load histories during the lifecycle or during the manufacturing processes and pass on gathered information to subsequent component generations in a continuous process of evolution. This paper further discusses the benefits of the depicted nature-inspired approach for nowadays manufacturing systems. In the future, the combination of genetics and intelligence in components will lead to new applications for maintenance, production management and product design.

KEYWORDS: Manufacturing, Component Design, Production Engineering

1. INTRODUCTION

The life-cycle of a product can be separated into different phases like concept development, product design, prototyping and testing, process planning, production, delivery/installation, service and the final removal/disposal phase [1]. Besides the apparent forward interdependencies, further backwards interdependencies should be considered representing feedback loops from the subsequent phase to the upstream process. For example, the real load history of a structural component is the indicator for further improvements of the design or the
material in the concept phase of the next component generation. Therefore, loads for a structural component need to be measured during the usage of the part and the relevant information has to be returned to the design department. During the life-cycle, different type of information can be gathered for the continuous improvement of the product or the involved processes. Nowadays manufacturing environment is characterized by a growing number of sensors for industrial monitoring in order to perceive further information for immediate responsive systems or further design improvements. A major direction of research in this area is the development of smart configurable wireless sensors. Widely used devices in manufacturing are active or passive RFID-tags which replace the paper travellers with bar code. The major advantage and application of the RFID technology are the unique identification of a part and the resulting precise traceability during the production or lifecycle. In novel approaches from the area of production management, RFID-tags enable the development of agent-based control leading to self-controlled components during the production phase [2]. Further concepts aim at the tracking of components during their whole life-cycle [3]. As these sensors are placed directly on the component, previously planned operating or monitoring parameters of the part or the manufacturing machine can be updated in real-time and thresholds for interference are continuously adjusted by real data. Thus, the trend of development is towards the realization of sensing components with enhanced capabilities in terms of information processing and storage.

A major drawback of the conventional approaches lies in their physical implementation. Physically adding a separated device to a component underlies several restrictions as the tag might lose contact, it can only operate in certain ranges, its position depends on the surface and the geometry of the part and some positions might be inaccessible even though loads are of high importance in this area. At the Collaborative Research Center 653 (CRC 653) at the Leibniz Universität Hannover, alternative methods for sensors, data storage and data processing have been sought in order to overcome the current limitations of nowadays concepts. Thereby, nature has been the model for a next generation of components which is described in the following.

1.2 Nature-inspired approaches in engineering

Ever since, engineers aim for novel and innovative approaches for product design, product functionality or product capabilities with the aim of gaining new customers or realise unexpected solutions for engineering problems. Closely studying the form, functional characteristics or social behaviour of natural objects can provide unexpected inspirations for new products, technologies or organization management. Tracing back the history of nature-inspired approaches leads to first technical applications like for example the nose of dolphins influencing the design of ship hulls or the first flying machine constructed by Leonardo da Vinci inspired by
the flight of birds and bats [4]. Besides the functional design of a product, also surfaces have been investigated and nature-inspired approaches have let to the development of new coatings and surfaces with the riblet-effect for reduced flow resistance motivated by the analysis of the skin of sharks and dolphins or with a high water repellence inspired by the characteristics of the Lotus-flower [5, 6]. Further improvements have been achieved based on nature-inspired approaches like winglets at aircraft wings copied by the form of the wings of buzzards and vultures or flexible handling devices originated by the tail-fin of fishes.

The approach of the CRC 653 goes far beyond copying designs. In nature it can be observed that creatures are able to react to changes in their environment and to adapt their behaviour as well as to pass on the genetic material in the recombination process of evolution. The idea of the CRC 653 is to learn from the processes in nature and to transfer the knowledge in order to realize a new generation of components with the capabilities of sensing influences from their environment and to inherit their genetic code during their lifecycle to the next generation of components in the concept phase. Before depicting the approach in detail, the foreseen enhancement of products by this idea is illustrated.

1.3 Evolution of product characteristics

From generation to generation, nature achieves a new population of life-forms for changing and dynamic environments in the process of evolution. Mechanisms of biological evolution are an archetype for continuous adaptation. The modification of the current status and the process of the selection of the best chromosomes can be transferred to nowadays manufacturing technologies and the evolution can be described for the component design. Whereas in the beginning of the evolution the focus is on realizing the required functionality of the part, with on-going knowledge about the usage of the product, e.g. the customer behaviour and expectations as well as the maximum loads, the product can be optimized in term of ergonomics and light weight construction. With increasing understanding of the considered system, sensors can be integrated at sensitive positions on the component enabling a monitoring of the current status and giving a feedback to control units. If connected to a control unit, the component gains further capabilities in terms of autonomous control and data processing. All these product generations have in common, that an external sensor has to be added to the component. Thus, the next evolution step is to realize components which integrate all these capabilities into themselves. The latest generation of components includes parts with the inherent capability to sense loads during the lifecycle, to inherently store the information and to communicate the information in order to pass on the significant information for the design of the new component generation (Figure 1). New challenges result for this
new generation of components in terms of product design and manufacturing.

2. GENTELLIGENT COMPONENTS IN THEIR LIFECYCLE

Being inspired by the natural evolution of humans, animals or flora, the latest generation of components is described as gentelligent components. Within the CRC 653 “Gentelligent Components in their Lifecycle” at the Leibniz Universität Hannover, technologies are developed enabling these future components with genetic and intelligent capabilities. The objective is to eliminate the physical separation of components and corresponding data as well as enabling the inheritance of information gained during the components lifecycle in order to improve the design or manufacturing of the next component generation based on the biological principle of evolution [7]. Representatives of this group are for example smart or sensing materials with the capability to perceive information from the environment and process this information to the next generation. The concept of gentelligent components is depicted in Figure 2.

The difference to nowadays systems is the approach to eliminate the physical separation of component and information which makes the integration of external sensors necessary superfluous. Nonetheless, the requirements on gentelligent components although comprise a precise product identification, an accurate load measurement, a component design based on the real load history, an effective protection against plagiarism and the enabling of self-organizing manufacturing systems.
2.1 Applications of Gentelligent Components

Different technologies are applied and alternative approaches are executed for realizing gentelligent components [7]. A selection is presented in this paper. One novel approach is the development of magnesium as a lightweight construction material which is enhanced with gentelligent properties. A composite structure made of magnesium and ferromagnetic particles is produced in a casting procedure leading to the creation of magnesium with magnetic capabilities.

![Magnetic data track](image-url)

Figure 3: Development of casted magnesium with self-inherent data-storage and sensing ability
The aim is to enhance the capability of future component generations in terms of self-inherent data-storage as well as sensing ability [8]. The component can serve as a sensor itself and relevant information can be collected non-destructively with the magnetic field sensor. Innovative alloys on the basis of magnesium and samarium-cobalt-copper with microstructures containing intermetallic phases with soft magnetic properties have been developed within the CRC 653 at the Institute of Materials Science Hannover [9]. Due to the Villari-effect, the component can further serve as a sensor the recordable magnetic field changes if mechanical stresses are applied on the component. The data can be written inductively and read in a magneto-optical way. Therefore, an inductive write head has been developed which magnetizes the magnetic particles in the magnesium leading to a reorientation of the particles in the component. For reading the data, the principle of the magneto-optical Kerr-effect has been implemented. A binary coded bit string was successfully written and read. The concept is described in [10] and depicted in Figure 3.

In another approach within the CRC 653 at the Institute of Metal Forming and Metal-Forming Machines Hannover, a material inherent load sensor based on load-induced martensite formation has been developed. In metastable austenitic steels, mechanical strain can render a transformation from austenite to martensite which can be detected non-destructively using eddy current sensors [11]. Through the local embedding of stampings at defined positions during the production process of a gentelligent component the initial martensite content is defined. The stamping furthermore increases the sensitivity of the component if external loads are applied in terms of higher martensite development (Figure 4).

![Figure 4: Principle of load-induced martensite formation](Pictures: ©IFUM Hannover (CRC 653, Sub-Project S2))
enabling the differentiation between different types, directions and amounts of load.

The last example for gentelligent components reveals the possibility of non-destructive damage detection in components made of metastable austenitic steels with a great benefit for the future maintenance of these parts and gentelligent components lead to a variety of new applications. For example, during the lifecycle of the component, new maintenance measures like pro-active monitoring systems are applicable for structural components [12]. Furthermore, gentelligent components can be used for on-line process monitoring based on real-time data from the workpiece in terms of cutting force stability in machining processes or for the development of agile planning methodologies enabled by the self-inherent data-storage and sensing capabilities [13, 14].

3. CONCLUSION

In the presented paper, a nature-inspired approach for a new generation of gentelligent components has been depicted by means of research carried out within the CRC 653 at the Leibniz Universität Hannover. In the future, gentelligent components will close the physical gap of information and component leading to a new paradigm of manufacturing beyond RFID. Further application of sensor integration can be avoided and precise part identification is realized, vital enablers for future sustainable manufacturing systems.

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