Hartmut Janocha
Editor

Adaptronics and Smart Structures

Basics, Materials, Design, and Applications

Second, Revised Edition

Springer

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With 432 Figures and 17 Tables

Springer

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Preface to the 2nd Book Edition

The coined word *adaptronics* describes technical fields that have become known internationally under the names smart materials, smart structures or intelligent systems. The term adaptronics was originally formulated by the limited liability company VDI-Technologiezentrum in Düsseldorf, Germany. In the autumn of 1991 the term was sanctioned by a board of independent experts. Initially, the term encompassed all functions of traditional control loops, which are applied to generate adaptive behaviour, i. e. adaptronic systems or structures that adapt automatically to different operating and environmental conditions. Furthermore, in contrast to conventional control loops in which each functional element is a separate component, adaptronics is characterised by multi-functional components. Thus, several application-specific functional elements are embodied in one single component (e. g. a self-sensing actuator), which is preferably integrated into the structure or the system. The intention is to build lightweight adaptive systems and structures to be as simple as possible, with the ultimate goal of reducing the material and energy resources needed for implementation and operation to an absolute minimum.

Given this background it is obvious that apart from the technical requirements for automation, modern functional materials are an essential basis for the successful design and application of adaptronic products. Today, the most well known of these materials are shape-memory alloys, magnetorheological fluids and piezoelectric materials. An old example of an adaptronic product that has been cited numerously are glasses made of photochromic glass. These glasses automatically change the light transmission depending on the surrounding light intensity by performing sensor, actuator and closed-loop control functions for transmission adaptation. Looking to other technical areas, adaptronics has great potential for application in vibration and noise reduction. Fields of application include, for instance, the automotive industry, mechanical engineering, architecture as well as the aerospace industry. Other kinds of application scenarios focus on nature trying to simulate fundamental 'vital functions' by means of adaptronics. One aspect is the ability of biological systems to recognise and automatically correct local disfunctions in their structure. Naturally, this feature is also desirable for technical systems and structures, especially in areas where safety is essential (civil structures, aircraft).

With this book the editor and the publisher have tackled the task of presenting the state of the art of this both fascinating and demanding technological-scientific field. In this 2nd. book edition the contents from the 1st. edition from 1999 have been updated and extended corresponding to the development progress. The outline, which has proven worthwhile, has been maintained: following an introduction describing the aims and the content of adaptronics, subsequent chapters present the ‘scientific pillars’ from the viewpoint of the various basic disciplines involved. Thereafter, important components of adaptronic structures and systems, such as actuators and sensors, are described. The remaining chapters are dedicated to applications of adaptronics in the various technological and biological/medical fields of daily life, and an outlook towards future developments concludes the book.

It is obvious that no one single person can master all the specialist knowledge involved in such a detailed and varied field as adaptronics. Thus, we recognize both a necessity and a great opportunity in bringing together, in a fundamental work, the knowledge and the experience of proven experts from across the range of adaptronic disciplines. The editor is proud of the fact that numerous experts from all over the world have supported him in performing this task. To all of these he expresses his gratitude. It will not escape the attention of the reader that, in their nuances, viewpoints about adaptronics may diverge somewhat. However, this situation is actually both attractive and stimulating. It is also hardly surprising in view of the fact that adaptronics has only begun a few years ago, to establish itself as a discipline in its own right.

With this background in mind, the editor and publisher hope that the 2nd. edition of this book will also become a useful source of information and ideas, which a large number of readers can rely on time and again. Perhaps it will help some readers to discover their interest or their vocation to actively and creatively support the field of adaptronics along its path to maturity.

Finally, the editor would like to thank his co-workers Petra Detemple, Chris May and Andreas Biehl for their untiring help in transferring the manuscripts and figures, which the contributing authors had presented in widely varied forms, into a uniform format. He also thanks the publishing house Springer-Verlag for the appealing outward design of the book.

In conclusion, the editor wants to assure the critical readership that its constructive comments about the conception, content and presentation of this book are welcome and will be taken into consideration, if possible, in future editions.

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Juli 2007 *Hartmut Janocha*

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1 Adaptronics: A Concept for the Development of Adaptive and Multifunctional Structures

D. Neumann

1.1 What is Adaptronics?

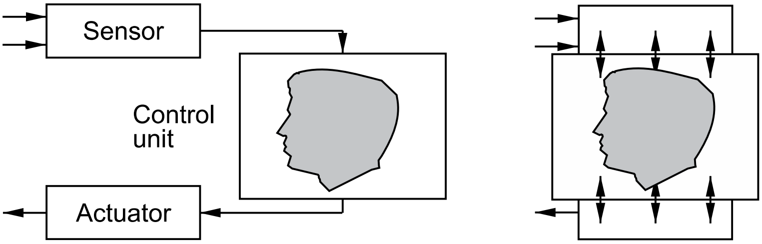
In German-speaking areas 'adaptronics' is the comprehensive generic term for disciplines that, on an international level, are known by names such as 'smart materials', 'smart structures', 'intelligent systems' etc. The technical term adaptronics (Adaptronik) was created by the VDI Technology Centre and was submitted as a proposed name to a body of experts. Within the scope of a workshop, fourteen experts from the fields of research, development and technology management agreed on the introduction of this new technical term, along with the pertinent definition and delimitation. This was the origin of the term 'adaptronics'.

The term adaptronics designates a system (and its development process) wherein all functional elements of a conventional regulator circuit are existent and at least one element is applied in a multifunctional way. The conformity with a regulator circuit guarantees that the structure shows autonomic adaptive characteristics and can thus adapt itself to different conditions. The limits to the classic control circuit, where normally each single function is achieved through a separately built component, are fixed by the use of multifunctional elements (functional materials). These elements are decisive for making such a technically utilizable system less complex.

An adaptronic system thus is characterized by adaptability and multifunctionality. The aim is to combine the greatest possible number of application-specific functions in one single element and, if appropriate, in one specific material (see Fig. 1.1).

1.2 Examples of Adaptronic Systems

A prime example of an adaptronic system is spectacles equipped with photochromic glass. A photochromic glass which, in dependence on the external ambient brightness, darkens or lets move light through in a self-regulating manner, combines all necessary application-specific functions. It not only covers all three elements of a regulator circuit – the sensor, the actuator and the controlling unit – but also covers the shaping and optical functions as further interesting material properties. This example shows that it is possible



a **b**

Fig. 1.1. Transition from **a** a conventional system to **b** an adaptronic system

to successfully combine all functional components of a system into one single element, in this case even into one material; further external components are no longer required. The spectacles glass represents a complete functional unit.

Examples for adaptronic systems with a more distinct visionary character are window panes whose transparency automatically regulates itself or can be adjusted within seconds by pressing a button; and hydroplanes whose aerodynamic profile adapts itself to the prevailing flight conditions.

Taking an adaptronic shock absorber as an example, Fig. 1.2 shows four different levels of creating an adaptronic system. On the basic level it is first necessary to produce materials that have both suitable passive qualities and application-specific functional qualities. Depending on the specific application, passive qualities can be of a mechanical, chemical, thermal, optical or electrical nature. For instance, required characteristic features can be resistance to high and/or low temperatures, high mechanical stability, light-transmitting capacity, or good electrical conduction. Functional qualities can be structural changes, changes in the dynamic or static features, or in the chemical, electrical, thermal or optical properties. They can, among other things, manifest themselves in a change of transparency depending on the luminous intensity, in a voltage-dependent change in viscosity, or in a temperature-dependent change in dimension or shape.

The example of an adaptronic shock absorber shows how the electrorheological fluid is simultaneously used as a 'classic' absorber fluid and as an actuator (if necessary, additionally as a sensor). This use is made possible by the capacity of such fluids to change their viscosity to a vast extent in less than a second when they are influenced by an electric field.

Functional qualities can, however, only be used in terms of adaptronics if there is success in combining the specific release phenomena with the respective desired functions. What is therefore required in the conception of multifunctional elements (level II) is the release and specific use of the material-inherent options. For this purpose it is necessary to make use of release phenomena of a physical, chemical or biological nature on material in such a way that, as necessary, several effects can be combined by taking well-directed action. For example, the application of electrorheological fluids

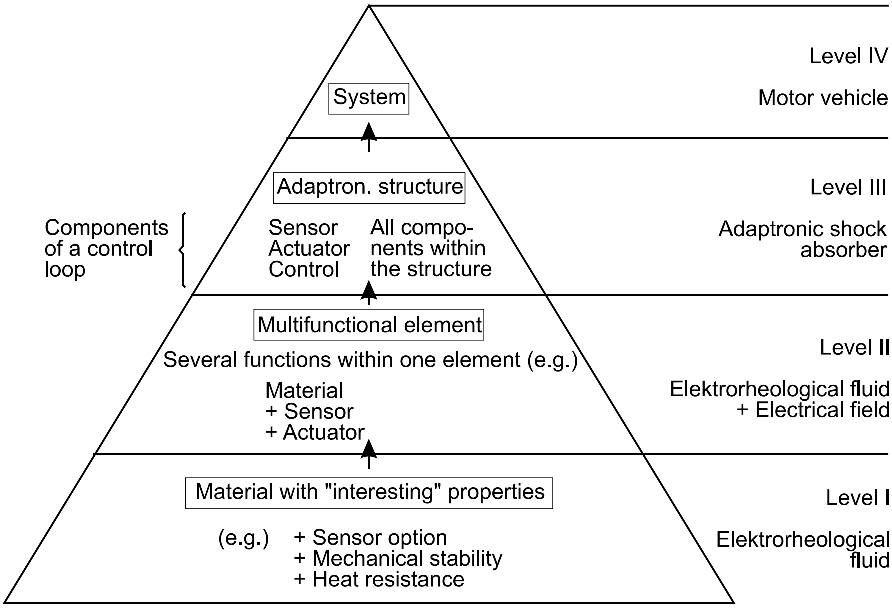


Fig. 1.2. Adaptronics: link between material and system

in an adaptronic shock absorber requires the production of an electric field, as well as the recording of a motion-dependent, variable intensity of current (i. e., use of the sensor effect). Hence, the multifunctional element does not exclusively consist of the electrorheological fluid but necessarily also of an electric voltage and field-producing electrodes.

At the structural level, multifunctional elements must be supplemented to form a complete regulator circuit, always aiming at building up a structure that is marked by minor complexity, low weight, high functional density, and economic efficiency. The successful achievement of this objective will normally depend on the degree to which the functional density is already in existence within the individual elements forming the structural components. In an ideal case – as in case of photochromic glass – all application-specific functions exist in one single element. The outcome will, however, not always be successful. For instance, the multifunctional element existing for the construction of an adaptronic shock absorber must be supplemented by a controlling mechanism, as well as by the structural components required to produce the electric field.

The system level – in the present example the entire motor vehicle – calls for the need to conceptualize during the creation of the adaptronic structure. For instance, the structural shape and damping characteristic of a shock absorber must harmonize with the overall design of a moving gear. Here again, the aim is to optimize the functionality of the entire system.

1.3 Multifunctional Elements

Functional materials constitute the essential basis of all adaptronic systems. The made-to-measure production of functional materials, wherein several functions are interlinked at a molecular level, is therefore of special importance. The more application-specific functions are combined in one single element, the bigger is the advantage in terms of an adaptronic system optimization. Multifunctionality can, however, not be a characteristic feature of an isolated element, but should always manifest itself by meeting user-specific requirements within a system interrelationships. Thus the same element can produce a decisive compression of functions in a given case (A), while it can be completely worthless in a given case (B).

Multifunctionality is by no means required to be coupled to highly sophisticated functional materials. Sometimes amazingly simple concepts lead to a problem-adjusted solution. It is, for instance, conceivable that a gas-filled balloon regulates the volume flow in a fluid flow tube in a temperature-dependent manner. The gas expands with rising temperature, whereupon the balloon reduces the uncovered tubular cross-section. If the temperature decreases, the volume flow is increased along with a smaller balloon cross-section.

This example shows that no limits are set to the users creativity. Mechanically simple solutions are often advantageous compared with high-technology concepts: they are not only more often reasonably priced, but also frequently marked out by greater functional safety. Made-to-measure solutions, however, can in most cases not fulfill their function without high-technology concepts of material scientists.

Materials represent the essential basis for all multifunctional effects. The conception of multifunctional elements is therefore mainly based on the made-to-measure production of functional materials, wherein several functions are interlinked at a molecular level. However, the fact that this is not sufficient in all cases is clearly shown by taking adaptronic shock absorbers as an example, because some effects can only be produced if several materials are combined in suitable interconnected layers or other compounds.

Functional materials, which are characterized by a high potential of functional and application options, are amongst others: shape memory elements; bimetals; electrorheological, magnetorheological, thixotropic and rheopex fluids; piezoelectric elements; electrostrictors; magnetostrictors; chemochromic, electrochromic, hydrochromic, photochromic, and thermochromic elements; and functional gels.

1.4 Fields of Technology and Application

The foregoing explanations show that a basis for adaptronic structures is created in numerous different disciplines of science. The range of applications covers various physical, but also chemical and biological technologies