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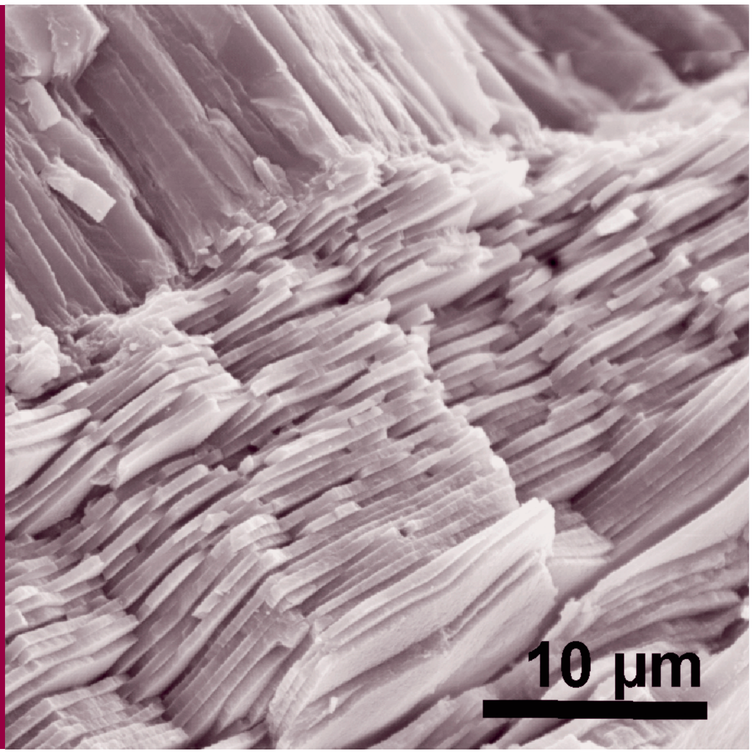
Potential and prospects for application of bionics

Summary



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SUMMARY

Bionics attempts to learn »from nature«, using scientific means to solve technical problems. With bionics, approaches in research and development are understood which pursue a technical interest in knowledge and, while searching for solutions to problems, inventions and innovations, gather knowledge from the observation and analysis of living systems and transfer this knowledge onto technical systems. The concept of the transfer of the knowledge of functions and structures of living systems onto technical systems is central to bionics.

Bionics holds a great fascination for the general public. To conceive of living organisms as high-tech systems and marvel at their »technological efficiency«, opens up the possibility of overcoming the frequently observed contradiction between nature and engineering. The »promise of bionics« also implies that through bionic approaches, a more natural, closer-to-nature or better adapted technology will be put into practice. This would mean that more suitable characteristics, such as fitting into natural cycles, lower levels of risk, fault tolerance and environmental compatibility would become possible. This conviction provides an essential incentive for many bionic engineers as well as a central legitimisation of their approaches.

In order to substantiate these perceptions, references are made to the characteristics of problem solving innatural living systems, such as multicriterial optimisation under variable marginal conditions, use of material available in closed cycles. These arguments help to make it clear that bionic solutions to problems accordingly have potential. Whether this potential can also be put into practice in individual instances and under what circumstances this may happen remains to be seen. Bionic problem solutions are therefore not per se lower-risk or more environmentally friendly than traditional technical solutions. This is because an evolutionary optimisation takes place in nature according to different criteria and conditions than are applicable to technical problem solutions. The transfer of the knowledge gained from living systems into a technical environment is not trivial procedure, which can reduce the potential of bionics to nothing or even transform it into hazards.

For this reason the relationship of bionics to nature is split. Nature has on the one hand an exemplary character in bionics, but is on the other hand not of interest as nature itself, but rather »only« as a model for technical solutions to problems. For this reason bionics casts a technical eye at nature, as opposed to an original »direct« look at nature as nature.

THE BIONICS SCENE – AN OVERVIEW

There are as yet no firm divisions within bionics. Due to the fact that the bionic notion of transferring functional and structural knowledge from living onto technical systems could achieve something in probably almost every technical field, there is no separate classification within bionics. Classical bionics refers to bionic applications e.g. in the fields of building and air-conditioning, constructions and equipment, styling and design, procedures and processes, materials and structures as well as locomotion. An important topical field of research with considerable potential for applications is that of new materials. New bionics follows current developments in nanotechnology and evolution biology. On the one hand it comprises micro-approaches in nanobiotechnology, prosthetic applications and neural control inspired by molecular biology; and on the other hand developments in information technology and in the organisation of collective processes motivated by evolution theory.

German bionics research is thematically wide-ranging and has a very good basis. The segments of bionics researched and the fields of application encounter attractive markets to a large extent both at home and abroad. Both established fields (such as those of new materials, functional surfaces or in design) as well as recently developing sectors of bionics research (such as prosthetic developments) are out to make innovative contributions to socially and industrially relevant research and development. The attribute »bionic« has a positive connotation in public awareness and is readily used for promotion purposes.

Alongside the USA and Great Britain, which are as well positioned as Germany, France, Switzerland and Austria in particular are deeply involved in bionics. Japan – particularly in the locomotion and robotics sector – and China (marine bionics) are expanding their engagement. The information situation is however in part quite poor, in particular concerning Russia and the USA, as many bionics projects are located in military research and accordingly subject to secrecy.

Bionics in Germany is characterised by partnership and co-operation instead of rivalry and competition. This is demonstrated by the central concentration of competences in the BIOKONnetwork and the assignment of members into thematically differently oriented specialist teams, in which the scientific exchange of ideas and the use of synergies is at the centre of attention. This concentration is also a strength when compared internationally. Whereas in other countries the identification of actors and projects in the field of bionics is often difficult and requires lengthy investigations, the BIOKON Internet presence offers an excellent overview of German bionics research, its actors and their corresponding specialist priorities as well as numerous links and opportunities for making contact.

In many cases however, bionics is born of the initiative and the commitment of individuals or R&D institutions. The critical mass for bionics, in order to significantly shape the process of innovation, cannot be achieved on either a national or an international scale. Firstly, this has certainly to do with the fact that bionic solutions are strewn across a very wide range of fields of application, so that a particular contribution and thereby influence in the – for the most part large-scale – fields of application has to remain minor. Secondly, a number of barriers to a greater role for bionics in innovation systems can also be detected. These include comparatively long development periods for bionic products and processes, a certain reserve on the part of industry, conflicts between universities and industry, an albeit increased, but nonetheless marginal level of research promotion, the absence of bionics to a large extent in scholastic and university education as well as a lack of communication.

NEW MATERIALS

Biological materials are designed to be resource efficient and are distinguishable through a high level of stability and functionality with relatively low material usage. Moreover the materials used are as a rule readily available in the environment (the principle of opportunism in the selection of materials). There are no high-performance materials to be found in nature, but rather simple materials with efficient inner structures, which are perfectly synchronised to the respective biological design and thus display amazing mechanical characteristics from a technical viewpoint.

Through their combination as multi-component materials or composites, many materials stand out from a technical viewpoint through an ideal combination of what are often contradictory material properties, such as strength and elasticity. Multifunctionality makes a substantial contribution to the efficiency of biological materials. Their working life is adapted to the functions which they are intended to fulfil. Due to their simple chemical basis all of the materials are biodegradable and thereby constituents of a natural cycle. In order to illustrate the material-bionic aspects, several fields of research are listed as examples:

> Taking bioceramics as an example, problems of definition become clear which do not however present obstacles to practical applications: The crystalline of

the ceramics (with, for example, hostile to life manufacturing temperatures of over 1,000 °C) is rather more in contrast with things biological and living. In the meantime »bioceramics« represents a highly dynamic, extremely promising branch of ceramics oriented material sciences.

> A further example is mother-of-pearl, which is in the focus of research interest, because it stands out through a high degree of hardness at the same time as great breaking strength. Mother-of-pearl is among other things tougher than today's industrial ceramics. Potential areas of use include the sector of medical technology (implant materials), as the non-ceramic materials used today are often problematic in terms of their biocompatibility.
> A high potential for technical applications is expected from adaptable materials (smart materials). Self-repairing (wound healing) is an adaptable characteristic of all living organisms. Results of investigations suggest that the self-repair processes in plants are achievable in technical products. At the moment e.g. self-repairing membranes are being developed for technical applications. The interaction of »sensor, control unit and actuator« can be used for biologically inspired walking (robotics, biomechatronics).
> Bionically structured coatings meanwhile offer properties which go far beyond the well-known lotus effect (self-cleaning in connection with water). There is a range of products on the market in the meantime (e.g. house paint, non-stick coatings, riblet sheets).
> Natural adhesive cements are still in some cases technically superior (e.g. long-term adhesion under extreme conditions such as salt water for instance). Furthermore all the adhesives used in nature are environmentally friendly. In addition it is also a question of the development of detachable bonds, with the goal of making fixed joints between materials without welding or gluing.

What can be noted in all of the examples listed is, that in order to arrive at »technical« solutions on the basis of natural-scientific explanations (e.g. molecular biological principles), pure research still needs to reach a »certain maturity« in many cases and existing products need to be further optimised.

The number of material based developments is so vast, that a classification as far as the status of research is concerned is difficult. Nonetheless it can be noted that bionics has an important role to play in future material developments. For the properties of natural materials – such as adaptive abilities, multifunctionality and a resource efficient structure – are at the same time also the properties which are the objectives of current materials developments. A prerequisite however is a deeper understanding of the interaction of the function and structure of natural materials, as well as the mechanisms of creation, transformation and self-healing.

In the fields of car manufacturing and structural engineering/architecture, bionics can make different effective contributions to (future) technologies (e.g. lightweight construction based on bionic models, fluidic optimisation of vehicles, development of special rims and tyre treads, supporting structures oriented around the distribution of forces, transparent insulating materials). While doing so, its immediate »closeness to nature« – both as an exemplary function and as mostly the first procedural step in bionic research – does not per se guarantee a sustainable practice-oriented application either today or in the future. A characteristic apparent in implemented bionic solutions is that they bring a large number new development and product ideas in their train – not necessarily exclusively of a bionic nature. This is shown by the example of self-cleaning, superhydrophobic (especially water-repellent) surfaces and materials.

NEW BIONICS

Nanobionics and/or nanobiomimetics denotes research activities, which make approaches to solutions from nature (or from cells) available for human needs and manufacturing processes. These fields of research are oriented towards molecular biology and profit from advances in nanotechnology. Corresponding developments are still in the middle of the basic research phase, even when concerned with such concrete objectives as the technical reproduction of photosynthesis. Where the bionic approaches that have to date been followed up were characterised by the transfer of possible solutions from nature onto technical systems, within the framework of nanobionics interventions in nature are on the agenda at the same time, reaching as far as the construction of artificial cells and thereby finally to the creation of artificial life in synthetic biology. The establishment of the analogy of bionics to date with nanobionics proves itself to be problematic at the latest, when there is intervention in the evolutive processes themselves, therefore when »man takes evolution into his own hands«. With the shortening of the natural time periods in which evolutive processes take place setting in, new types of risk can be created. Therefore in spite of all the fascination with nanobionics, careful accompaniment by risk research and technology assessment should follow.

Advances in prosthetic applications contribute to a development reaching from the morphological establishment of an analogy (for example the ear trumpet) via a complete abstraction and rejection of the model back to a continuous convergence with the natural processes – in the sense of a »replication« of the underlying complex sensorial and information processing mechanisms. It has increasingly to do with a more or less exact functional reproduction of nature. This »transitory« understanding of bionics (from the analogy to the copy) can be illustrated on the basis of artificial arms and legs or dentures. With advances in science, the efforts and the scientific-technical possibilities increase to reproduce complete or at least partial limbs with the function required, or which even recreate natural functionality. A great deal of success has been achieved here, although an exact copy is still a long way off. Neurobionics (e.g. neuro prosthetic developments, biohybrid elements) is accepted by a large number of bionic engineers as a field of bionic research, as long as it has to do with learning from nature with an eye on evolutionary insights. Others however distance themselves from neurobionics for prosthetic applications, as this is more oriented towards the »substitution of senses«. Through the enormous advances in the understanding of biological elements as well as the technical progress in the field of miniaturisation and materials, it can be expected that neurobionics will nevertheless claim a clearer role in bionic research than previously in the years to come.

The application of evolutionary strategies is a further topical field of research in bionics. »Natural Computing« operates in information and communications technology with the principles of variation and selection, in order to identify »optimal« strategies under certain conditions through trial and error. In questions of the organisation of complex behaviour, whether it be the behaviour of a collective or the behaviour of individuals in the light of combinatory optimisation tasks, the phenomena of »swarm intelligence« have been under investigation for some time. This has to do with the modelling of the complex behaviour of ant colonies or swarms of birds for example, on the basis of very simple rules at an individual level, and to gain ideas from this for the solution of problems of social organisation.

In principle it can be observed in all of these technically and scientifically fascinating fields of »new bionics«, that considerable potentials for innovative technical opportunities are discernible, yet that the developments are for the most part still in the early stages. The bionic thought process is ultimately aiming for technical solutions to problems, but as a rule however it is still a long way from market maturity. The frequently used evolutionary principle of self-organisation has its own ambivalence and could lead to risks which are brought about by the increasing autonomy of the technology built upon this and the possible loss of control by mankind.

CONCLUSIONS AND OPTIONS FOR ACTION

Bionics leads to a considerable extension of the »toolbox« in the innovation system, in which technical solutions to problems in the world of mankind are learned from the enormous variety of »technical« solutions to problems in nature. This considerable increase in possibilities for human action already justifies special efforts to specifically exploit bionic potential where possible. The »promise of bionics«, of a more natural technology certainly contributes to the motivation of many researchers; this is however not at all necessary as an explanation of why bionics should be pursued and publicly supported. Here the argument for the development of a large pool of ideas for human purposes suffices entirely.

For a differentiated point of view of bionics and the working method practiced in this sector, a consideration of the whole process of innovation from its biological foundations (idea) right up to its technical conversion (product) is indispensable – also in order to be able to realistically describe the potential of bionics.

In order to establish bionics as a »pool of ideas« for innovations, one fundamental prerequisite is the development of strategies for the efficient filtering out of the relevant aspects for technical problem solving. Due to the enormous variety of »natural solutions to problems«, further systematisation and the availability of functional principles from biology would be appropriate. A further point is the focussing of research oriented promotion onto selected aspects (e.g. exploitation of knowledge, strategies for patent rights, structure of new promotion priorities).

A functioning interdisciplinary working method would at the same time be a central element of bionic developments. Here as well there are opportunities for improvement in the communication between different scientific disciplines. The existing network organisation in Germany should be maintained – also with regard to interdisciplinary aspects and the European level.

The application potential for bionics is extremely wide-ranging. Corresponding market potential is available, whereas relevant market research would however be necessary for a detailed picture. There is a lack of support options at a regional or even a national level for transferring or exploiting bionic developments for implementation in skilled trades or in medium-sized companies.

The positive connotation of the term »bionics« with the general public could be expanded, even against the background of having to convey an even clearer picture of exactly what bionics amounts to. This understanding would among other things also be a foundation for a better anchoring of bionic aspects in teaching and vocational training.

For a continuation of the treatment of the subject, the following areas offer themselves for consolidation:

> An investigation of life cycle assessment issues within the scope of overall observations of bionic product applications,
> Concretion of statements made previously on the »opportunities and risks« of bionics as a whole,
> A need for research in the sector of »new bionics« with regard to the thesis of »the promise of bionics« (context review, criteria, evaluation etc.), viability of the implicitly connected perceptions (robustness, error tolerance, adaptivity etc.), depth of intervention and effectiveness of »new bionics« on a molecular level and risks connected with that as well as detailed examinations for individual sectors (e.g. nanobionics, prosthetic applications),
> The carrying out of a differentiated comparative analysis with other countries (benchmarking),
> An investigation of the potential contribution of bionics to current ecological problems (e.g. in the sector »Building and Living«).

Germany is without doubt one of the major research locations for bionics worldwide. It is important that this high scientific standard of German research is maintained in the future. Its international reputation needs to be further strengthened, and bionic approaches must be sustainably and promptly integrated into industry's innovation processes. For the future it will firstly come down to passing on the knowledge from the research work which has already been conducted to the next bionics generation and above all to initiate a multiplier process through vocational training. Secondly, the bionic »way of thinking« must be more strongly integrated into education and vocational training.

Bionics offers a suitable framework for the specific and efficient transfer of knowledge from pure research right up to technical implementation. This transfer of knowledge is indispensable, in order to keep a long term technological edge. From the way that things stand at the moment bionics represents a technology option with immense potential.

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