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ENGINEERING DESIGN USING BIOLOGICAL PRINCIPLES

U. Lindemann and J. Gramann

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1. Introduction

Nowadays “bionics” is a well known word used by scientists, publishers as well as by politicians. The problem is that there are different definitions of bionics. One definition follows the idea of using biological principles within technical systems; another one tries to replace parts of the body by artificial systems like prostheses or implants. A third version, known as technical biology is the interpretation and understanding of nature by technical laws – and there are further interpretations too [Isenmann 2001].
In this paper we want to use insights into nature, so called biological principles when designing technical systems. We want to analyse biological processes and principles or use findings of biology to improve the design of products within mechanical engineering.

2. Bionic in Science and in Industry

2.1 Examples

In literature we find a number of examples of bionics: Some of those like the lotus effect are quite common. It was discovered in the middle of the seventies and published in a small marginal note in 1977. More than ten years after that the investigation of the importance and the possibilities concerning the technical usage of this effect started. There are a number of further examples described in literature like the skin of sharks used in aircraft industry, the dolphin shape used in shipbuilding, etc. Within the research community there are a number of activities in different areas of bionics as for example within the field of “red and green life sciences”. An important question for designers is how to use biological knowledge in engineering design.

2.2 Procedural Models

There are some procedural models available in literature like those of Rechenberg & Zerbst [Zerbst 1987], Hill [Hill 1998] or Vincent & Mann [Vincent 2002]. Rechenberg and Zerbst propose a procedure that checks the similarity of function, boundary conditions and properties indicating quality of technical as well as biological aspects. This procedure disgards the transfer of biological principles to different functions. Hill as well as Vincent & Mann are following the structure of TRIZ [Terninko 1998]. Hill supports a matrix of functions on one hand and of biological archetypes on the other hand, but further descriptions of the physical background and the boundary conditions are not available. Vincent & Mann propose an integration of biological principles in the data base of TRIZ, but this still has to be done.

2.3 Bionic in Industry and our Intermediate Result

The euphoria is quite impressing, but during daily business of an average engineering designer bionics has absolutely no importance. Some known exceptions are closely linked only to a few individuals. Sometimes matters are misused as a marketing point by using some biological comparison constructed after completion of the product development.

Because of these discrepancies we wanted to know more about the potentials and the procedure that fits to the engineer's way of solving problems. We also wanted to learn more about the difficulties of working with bionics.

3. Case Studies

Within the past two years we ran in total six case studies [Gramann 2004] in the field of bionics together with students, who were interested in the topic of biology in general and bionic especially. Within one type of the case studies we started with a given technical product, which we wanted to improve. The title of one of those case studies was "Improvement of the performance of vacuum cleaners".

Within the second category we started with a given phenomena in nature and we tried to find possibilities to transfer these findings to technical applications. The title of one of those case studies was "The principle of thermal zoning coming across at animal extremities"

3.1 The Vacuum Cleaner

The first case study was dealing with the improvement of vacuum cleaners in general and of the suction nozzle in detail [Fritsch 2002]. Searching comparable solutions in biology we tried to remember what we learned at school and we did some kind of a brainstorming. Finally we looked at insects like flies and the shape of their proboscis concerning the process of suction. Taking up lint we considered by investigating the tongue of snails or cats. At this point it was not too difficult to find researchers in biology who were experts in the fields of flies or snails. They were able to explain all the different characteristics of the biological patterns, but not to answer questions concerning the physical reason for the specific solution in nature, as this is not their field of interest in research.

Engineering designers and students of mechanical engineering then tried to transfer the observations and the supposed phenomena (the physical principle) into a technical solution. A number of different alternatives were created, sketched, and discussed; a lot of them were cancelled again.

The most efficient way to find out the efficiency of the supposed physical principle and the important parameters was the experiment, mainly the simple and fast experiment.

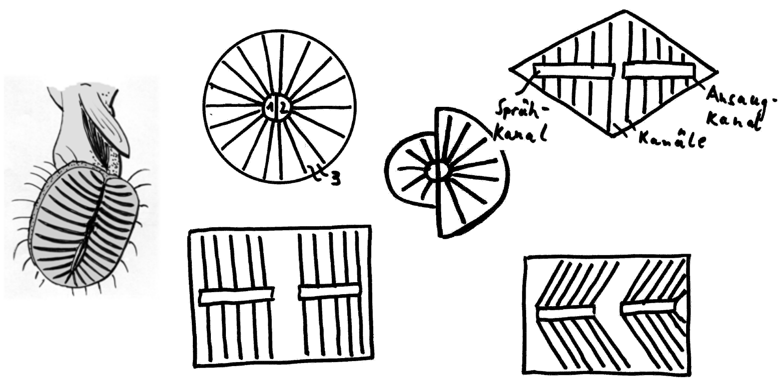

Figure 1. Some of the ideas to transfer the biological principle

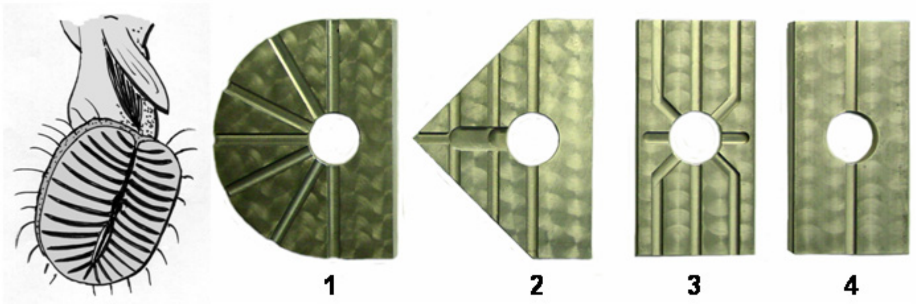

Figure 2. Hardware for orientating experiments (1, 2, 3 alternative solutions, 4 reference)

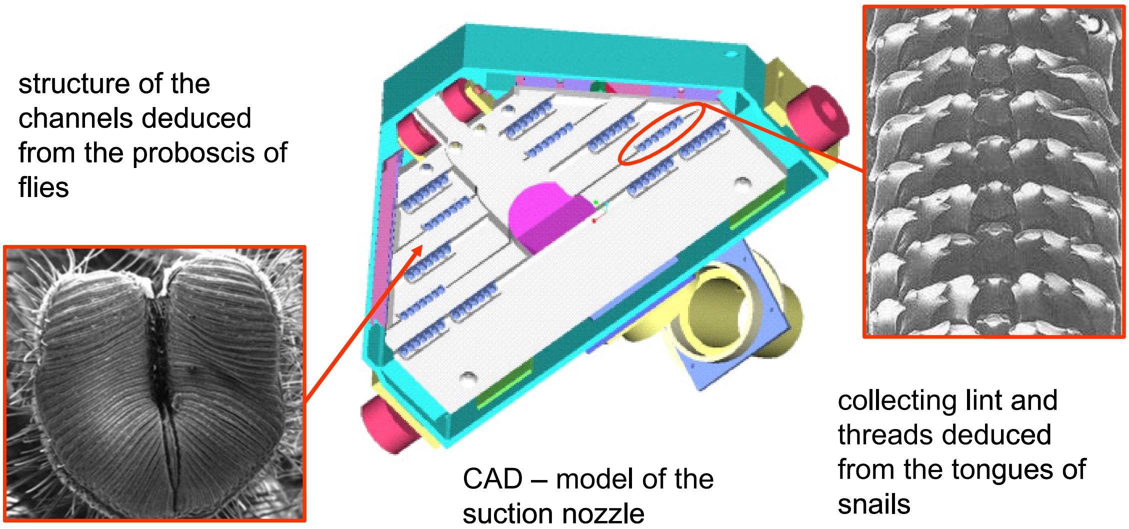

Figure 3. Result of the first step of development

The result of this first phase of the development was a new demonstrator (virtual and in hardware) of the suction nozzle with ideas resulting from our observation of the proboscis of flies and some specifics of the tongues of snails. The measured improvement seems to be important, but further tests are required to get a better understanding of the influence of all the parameters.
The first difficulty was to find some of the huge number of possibilities within biology you might look at. The main reason is the lack of the specific knowledge especially concerning the terminology. This problem is time consuming and in addition one has to understand the principle of all the different phenomena.

3.2 The Duck in Wintertime

Observing animals such as a lot of birds in wintertime one may ask, how they manage their heat balance, without high energy losses through their naked legs. Thermal isolation is an important matter in several fields of engineering, which was the reason of looking at this specific question in the second of the above mentioned case studies [Nopper 2003].
We asked a student to analyse the biological principles and to transfer the results to engineering and find some technical opportunities for new products.
Looking for example at the anatomy of a duck or a seal we will find - among other principles - some kind of a heat exchanger between the body and the legs. This heat exchanger, the so called "rete mirabile" prevents the loss of heat caused by the circulating blood through the legs. This biological principle is called "thermal zoning".

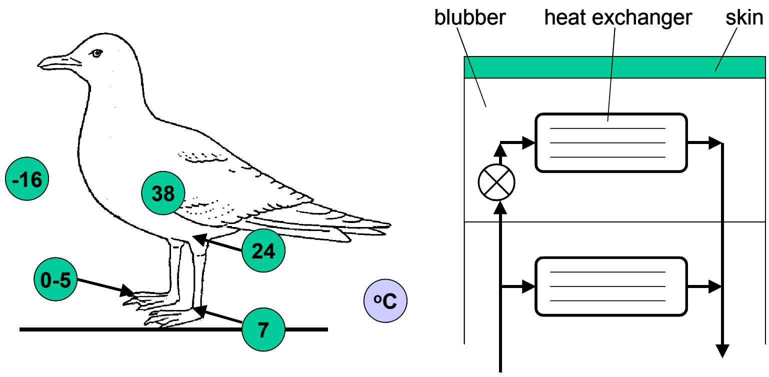

Figure 4. Temperature control of a bird and the principle of thermal zoning of a seal

The analysis of birds and other animals gave a number of insights. Having temperatures of -16°C outside of +38°C inside the body the heat flow is - at least for a relatively large time - not dangerous for the bird. To understand this principle is an easy task for an engineer, but quite often the physical description of the principle is not documented at all or it is documented in the language of biologists.
When this task of understanding is solved, the transfer to engineering starts. Where may the idea of thermal zoning make sense? In architecture and in the building industry this principle is well known. In mechanical engineering we may use it without knowing that this may be an important design principle at least under specific circumstances.
Within the study a number of 67 possibilities for a technical transfer have been produced as a result of the analogy and resulting ideas.
One technical solution was worked out and tested. In wintertime we have to prevent that an outside tap will freeze. One solution is to seal off the pipe by an inside purging valve, another possibility is an electric heating system located outside near to the tap. The new idea uses the principle of thermal zoning and is rinsing thoroughly the tap with already available warm water from the inside.

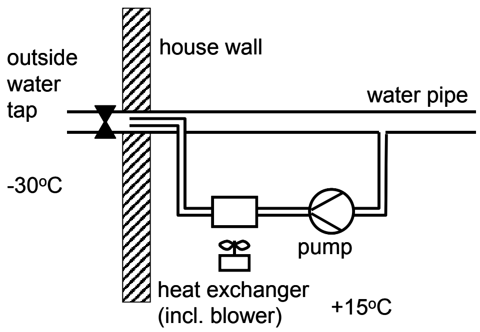

Figure 5. One idea for a new product to prevent the frozen outside tap

To find nice phenomena in biology requires some knowledge in the field of biology. There are matters which may be well known and because of that nobody wondering about it, why we have to have a critical view and creativity too. To transfer these findings to technical solutions and successful products is the even more challenging task.

4. Results

The experiences of working with bionics are that it requires real efforts to find correlated biological systems, to do the analysis of these systems regarding the technical intention, to deduce a technical solution out of it as some kind of transfer, and - not to forget – run the main engineering design process to develop the idea into a real product. We found out that bionics in the sense explained above is offering the possibility of generating new ideas for new products and the chance of improving existing products.

4.1 The Procedural Model

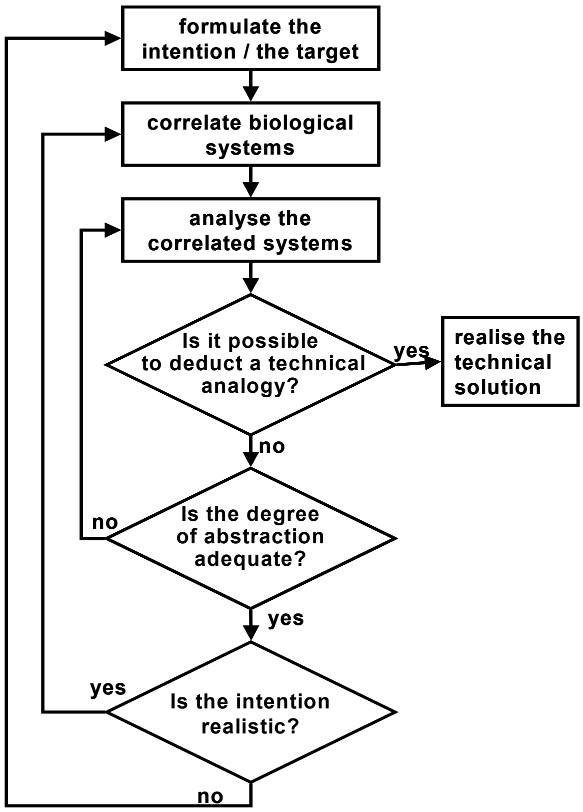

Figure 6. Our procedural model of doing bionics in the field of product development

We suggest a procedure for this kind of bionics, which includes elements of the ideas of Rechenberg & Zerbst [Zerbst 1987] as well as of the TRIZ [Terninko 1998, Hill 1998] methodology.
We start as usual with formulating the target or our intention and then we try to correlate this with biological systems, which have to be analysed. "Looking at the vacuum cleaner we had to find and analyse not only the proboscis of the fly, but also some hundred additional biological solutions."
With regard to the results we try to deduce technical analogies. "Transfering the tongue of the snail we failed, the system was working like a milling cutter and destroyed the carpet."
If this is not possible, we have to rethink the degree of abstraction. If this degree was not well adjusted we have to go back and work again on the analysis of the system. "We had to rethink the function of the tongue of the snail on another level of abstraction redefining the geometry to meet another physical effect."
In the other case we have to check our intention. If we still think that the intention should fit, then again we will have to correlate it with – maybe- some additional biological systems.

4.2 The Checklist of Biological Associations

The link between a technical function and the correlating biological principles was hard to find within all the case studies. In former methods this was quite often addressed as a question of the specific languages in engineering as well as in biology.
An important tool to decrease the effort is a structured checklist for engineers to find the key words of biology patterns as a kind of association for the required technical functions in engineering design. With help of these associations it is much easier and more effective to find adequate biological principles. The starting point for engineers is the formulation of functions in a general or a more specific way and the definition of the kind of object (solid, force …) of the function. The list of different associations (biological terms) helps to remember and to search. Even standard search machines in the web may supply enough input for the progress of the design process.

Table 1. Excerpt of the transfer checklist between technical functions and terms in biology

function I	function II	object / field / parameter	Associations
change of the state of aggregation	sublimate	solid	- (?) -
	vaporise	liquid	sweating (passive), spongy parenchym of a leaf (passive), bombardier beetle (brachynus) (active)
	condense	gas	nose passages, plants and animals living in desert, leaf
	melt	solid	spermaceti of sperm whales (physeter macrocephalus)
	dry / dehumidify	solid	splaying plumage (e.g. phalacrocorax carbo), dehydration in the intestine, shaking the fur, hydrophobic treatment by lipids, osmotic potential, seed of plants

5. Summary

The two kinds of case studies gave a lot of input to develop innovative products or at least start to develop a product in a new direction. Out of that a general procedural model for bionics was extracted and proven. To overcome one of the key hindering points for engineers a checklist was setup to build the bridge between functions in engineering and biological areas as a kind of associations to finally find adequate biological principles.

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Udo Lindemann, Prof. Dr.-Ing.
Institute of Product Development, Technische Universität München
85747 Garching, Germany
E-mail: udo.lindemann@pe.mw.tum.de