Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 9 (2011) 620–632

Engineering Procedia

TRIZ Future Conference 2007

Bionics in patents – semantic-based analysis for the exploitation of bionic principles in patents

Lothar Walter *, Ralf Isenmann, Martin G. Moehrle

University of Bremen, Institute for Project Management and Innovation, Wilhelm-Herbst-Straße 12, 23359 Bremen, Germany

Abstract

In this paper we present a sophisticated method to exploit bionic inventions in patents with the help of semantic patent analysis. This method enables users to visualize similarities in patent content in a semantic patent map. These maps could be used for strategic decision-making, e.g. for developing technologies and commercial usage and – no less important – for providing new insights to researchers and practitioners involved in bionics. A case study of US-based patents between 1976 and 2006 clearly shows that most bionic inventions are patented as medical applications in the area of surgery. Other fields of technological applications, however, apparently do not make use of bionic ideas for solving inventive problems. As a result, bionics may provide great potential for solving technical problems that needs to be exploited, e.g. perhaps to be carried out with the help of TRIZ.

Keywords: Bionics; Inventions of nature; Patents; Patent map; Semantic patent analysis;

1. Introduction

The theory of innovative problem solving (TRIZ) provides a proper methodological basis for the systematical generation of innovation. This method has been used very effectively in particular in R&D management for several years and fits quite perfect in the focal area of creativity and innovation management [1]. TRIZ is based on the experience made by thorough patent analyses. Bionics offers another opportunity for generating innovative ideas and implementing them into novel technologies. This alternative has drawn more and more interest in the past few years. Bionics focuses on the decryption of inventions working in nature [2, 3].

For bionics, it is distinctive to view nature as a model to learn from for technological and economic applications. This perspective of understanding nature as a model particularly stimulates creative thinking and opens up several options to make use of biomorphic metaphors, smart solutions working in nature, using its evolutionary strategies, and applying basic bio-cybernetic principles.

* Corresponding author. Tel.: +49-421-218-2256; fax: +49-421-218-8222 .
E-mail address: lwalter@uni-bremen.de .

doi:10.1016/j.proeng.2011.03.147

As an emerging field of research with relevance for science and academia, bionics has also become of increasing relevance for business and applications in industry during the last decade. Today, more and more companies are going to make more use of bionics. They undertake considerable efforts to exploit the full potential of nature's secrets, e.g. through using bionic principles for construction, design, and development of forward looking technologies and other smart innovations, to finally produce sustainable products and promising valuable services while gaining market success.

At first, nature's inventions are obviously not documented in patents and thus they are not protected through property rights. However, it becomes of increasing importance to identify bionic principles and extract the underlying and usually implicit and hidden knowledge for further technical development and economic usage. A procedure such as exploiting bionic principles out of patents remains to be a challenge, still. This raises a number of questions that need to be answered:

- Which patents do originate from nature's inventions? Which patents have its basis in bionics, and which inventions consist of bionic principles?
- What are the characteristics of bionic-related patents? What makes them unique and how could bionic-related patents be classified?
- Are there any patterns of bionic-related patents? What are the current foci of bionic-related patents, and what are the areas and fields they probably will be researched and patented in the near future?
- Which persons engaged in bionics are applying for bionic-related patents? Which companies are pro-active in bionic-related patents?

In this paper, patent analysis is proposed as a suitable method opening various applications finally used to answer questions like the above. The method of patent analysis itself is based on semantic structures. Using such a semantic patent analysis provides an opportunity for exploiting bionic knowledge out of patents and to visualize the knowledge landscape in so-called patent maps. These maps could be used for strategic decision-making such as technical development, economic usage and, not less important, for providing insights to researchers and practitioners involved in bionics. A case study of US-based patents between 1977 and 2006 reveals the benefits a semantic patent analysis may provide in comparison to a traditional approach of patent analysis.

2. Bionics – source of mapping technologies inspired by nature

During an evolutionary process of millions of years, nature provided an enormous pool of inventions. These inventions had passed the harsh test of practicality and durability in a changing and challenging environment. Hence, nature's inventions seem to represent smart solutions for a number of techno-economical applications with high performance while at the same time using resources like material, energy, space, and information efficiently [4]. These solutions could be used as inspiration either for copying or for fashioning, designing, and developing products, processes, services, technologies, and even whole industrial systems [5, 6, 7]. It is exactly this bridging effort that is the domain of bionics, an emerging interdisciplinary field of research with rapidly increasing business impact [8, 9], even for patent management [10]. Understood as a young scientific discipline, bionics deals systematically with the technical transformations and applications of underlying principles, procedures, developments, and phenomena working in nature, be it animals, plants or even whole ecosystems.

2.1. Introduction to and early history

The word "bionics" is made up of the terms biology and technics which means engineering in this context. Bionics as the term for the field of research primarily used in Europe is said to be coined by Jack Steele of the US Air Force in 1960 at a meeting at Wright-Patterson Air Force Base in Dayton, Ohio. Consequently, this meeting may be regarded as the early incarnation of bionics as a field of research. The intellectual roots of bionics, however, could be traced back even to earlier works in the history of the sciences, e.g. to the various works of Leornardo da Vinci (1452-1519). Rather closely to seminal US meeting, Otto H. Schmitt then introduced the term "biomimetics" in 1969 while the field increasingly involved with emerging subjects of science and engineering [11]. This is the term under which the approach of combining biology and engineering is often announced in the Anglo-Saxon area. The term "biomimetics" itself is derived from bios, meaning life, and mimesis, meaning to imitate or to learn from.

As a scientific discipline, bionics aims at analyzing biological systems and transferring the underlying principles, procedures, developments, and phenomena working in nature into technical implementations, finally leading to commercial products and services. A further milestone in the European history of Bionics was a symposium of the German Association of Engineers [12]. The leading experts in the field defined Bionics as “a scientific discipline, which deals with the technical implementation and application of constructional, processing, and developmental principles of biological systems” [12].

Since its launch nearly five decades ago, bionics has started from a smart idea, becoming a somewhat fuzzy concept, to give rise to a professional interdisciplinary scientific community. Institutional outcomes in Germany are for example the Society for Technical Biology and Bionics (GTBB) [13] and the Bionics Competence Network BIOKON [14]. Despite different terms used at the international level like bionics, biomimetics [15] or biomimicry [16, 17], the entire field now constitutes promising and powerful umbrella concepts with numerous tools, studies, publications and journals (e.g. Journal of Bionics Engineering, Applied Bionics and Biomechanics, Journal of Bioinspiration & Biomimetics, International Journal of Design and Nature), resources of research, and other characteristics that make it a discipline. The overall object of bionics is to study biological systems and transferring their underlying mechanisms into smart technologies improving commercial products and services.

2.2. Bionics – field of research

Nature’s inventions have always inspired human achievement and have led to technological progression often in the form of smart products, intelligent processes, effective algorithms, and cleverly structured systems [6, 15, 16, 18-24]. There are numerous examples of such successes inspired by nature such as the use of fins for swimming. Other examples were inspired by biological capabilities with greater complexity including the mastery of flying that became possible only after the scientific principles of aerodynamics were better understood.

In order to exploit the most from nature’s inventions, however, it is critical to bridge the gap between the fields of biology and engineering. This bridging effort is the key to turn nature’s inventions into engineering capabilities and finally to promising technologies and commercial products.

As a developing intellectual area, bionic’s scientific community with its young professional academic culture has a growing impact on government agendas and innovative research programmes [25-27], business applications in industry [28, 29], higher education programmes [6, 30], and management consultants [31]. Further, it is developing a degree of institutionalisation, at least to a certain degree. As its scientific contours are just emerging and still show dynamic behaviour, it seems rather difficult to provide a comprehensive overview outlining all the different facets, certain branches and full range of applications of bionics. However, there is consensus that bionics could be structured in terms of applied analogical research into three main areas:

- Construction bionics: structures of nature;
- Processing bionics: methods and processes of nature;
- Information bionics: means of data transfer, developmental, and evolutionary strategies.

In a more detailed fashion, this classification may be further refined according to certain fields of applications (fig. 1).

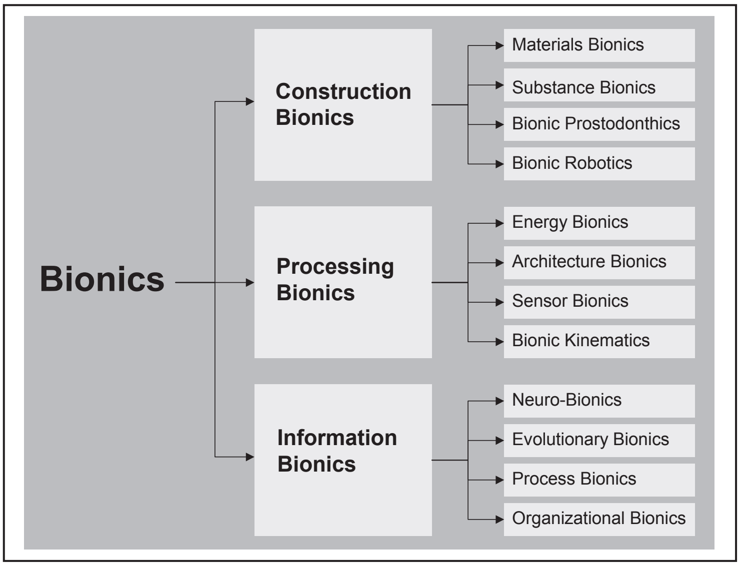

Figure 1: Bionics – its main areas and fields of applications [12].

2.3. Paradigmatic perspective and basic methodology

The paradigmatic perspective of bionics is the refreshingly different perspective of understanding nature as a model, compared to the orthodox behaviour in engineering research and management and organizational sciences where nature is usually interpreted e.g. in terms of "sack of resources", "biophysical limit", "something outside", or just "environment" as opposed to technology, economy, and management [7, 32-34]. This perspective characteristic for bionics is regarded as a feature of its distinctive identity that makes the field unique. Both, researchers and practitioners involved in bionics are looking for insights in solutions and dynamic adaptive behaviour of nature and its ecosystems for fashioning products, processes, services, technologies and even whole industrial systems smarter, i.e. more efficiently and probably in line with sustainable development [24, 33].

The eye-catching assumption of nature as a model is typically phrased in the form of the natural ecosystem metaphor and based on (picturesque, functional, or nomological) analogies between biological entities ranging from single phenomena and certain species to larger natural ecosystems – (seen as superior solutions or as mature cyclical economy) on the one hand, and technological entities ranging from smart products to industrial systems – (understood from a perspective of living systems on the other. Thereby, its proponents regard nature as being partly ideal in order to gain theoretical insights and to learn to deal with natural resources and services in practice.

This interpretation of nature as model in bionics – although not actually new – draws our attention immediately; it is intuitively appealing because it may originate from humanity's persistent wish for balance between natural ecosystems and technology driven industrial systems. In total, bionics' characteristic perspective indicates a fundamental shift of understanding nature, moving away from interpreting nature degraded to a mere material and energy base representing an object, or a limit towards a hypothetical model appropriate for deriving ecological innovations. In a broader sense, such a groundbreaking change could be called a paradigm shift: Nature is appreciated as a proper heuristic to adapt, apply, or learn from its phenomena, functionalities, strategies, principles, and in particular its dynamics [5, 6]. Borrowed from Simonis [35] who used the following credo for the closely related field of "industrial ecology" (e.g. [7, 34, 36]), the essence of the bionic worldview is to learn from the "wisdom of nature".

Reasoning on these fundamental methodological issues mentioned above is not restricted exclusively to the field of bionics; it is also of particular relevance for economics (e.g. [37]) and engineering sciences (e.g. [6, 24, 38-40]). Even research in ecology (e.g. [41]) and biology (e.g. [42]) as examples for mature disciplines with long traditions have come across such problems.

The paradigmatic perspective of bionics leads to a basic methodology used in bionics. This basic methodology could be best described through applied analogical research along two fundamental steps [5, 6, 43]:

- In a first step, nature's solutions which serve to a certain end and provide solutions for a specific set of problems have to be analyzed thoroughly (technical biology).
- In a second step, the newly described solutions can be implemented in technical applications with corresponding boundary conditions (bionics). This does not imply an exact copy of nature, which would not work in most cases. Bionics rather tries to elaborate the basic principles, so that they can be abstracted or detached from the biological model.

Subsequently, the abstractions are then transferred into technical applications. This is why the dialogue between biologists and engineers is probably the most crucial factor for a successful and efficient implementation of biological answers to engineering problems.

3. Semantic patent analysis

Genrich S. Altschuller stated that patent literature is an inexhaustible source of ideas [44]. However the ever-growing mass of explicit knowledge, as the continuous growth of patent applications shows, confronts the developers, scientists and patent attorneys with a number of emerging problems. It is nearly impossible to read all newly published patents without relying on modern information and communication technologies (ICT) because of short timeframes between published patents. A semantic patent analysis, however, can be used to face the challenge of understanding the vast amount of patents and extracting the inherent knowledge.

Semantics deals with the analysis of meanings in language. Invention Machine Coporation (based in Boston USA), offers a knowledge extraction software called Knowledgist™ 2.5, that uses semantics [45-47]. This software uses a semantic processor to detect the meaning and coherency in any English text. It then extracts all relevant knowledge from the chosen documents. Thus it allows its user to search, read, summarize and to texture the analysed documents. The core statements of all analysed documents are visualized in a Subject-Action-Object-Format (so-called SAO-structures). The action and its corresponding object display the problem or the particular task. Hence the subject is the solution of the problem, it is obvious that the discovery of a problem solving structure like this offers crucial advantages compared to a keyword search, that is offered by various search engines.

The listing of SAO-structures provides a rapid identification of problem solving structures and thus a systematic selection of relevant patents. Table 1 shows some exemplary SAO-structures that were extracted from the US-patent # 7,076,308 (a patent, where the term bionic is mentioned 29 times) with Knowledigst™ 2.5. A total of 151 SAO-structures were found, whereas the implemented standard filter was used.

Subject S	Action A	Object O
auditory nerve fibers	use	cochlear implant
bionic ear implant	provide	stimulation
cochlea stimulation channels	use	capacitor
externally wearable processor	employ	circuitry
magnitude of modulating signal	affect	dynamic range
new generation of cochlear implants	have	enhanced processing power
speech processor	employ	headpiece
sweeping tones	assess	Detectability
Threshold	represent	intensity of signal X
U.S. Pat. No. 4,400,590	describe	Electrical stimulation of predetermined locations

Table 1: Sample of extracted SAO-structures of US-Patent # 7,076,308 (Cochlear implant and simplified method of fitting same)

Besides the usage of a knowledge extraction software for determining SAO-structures, the software tool PIA (Patent-Information-Analyses tool), programmed at the Institute for Project Management and Innovation (IPMI), allows yet another computer based processing where semantic similarities are determined. PIA then uses a matrix to visualize the data sets that are bearing similarities. Those matrices compose the base for mapping patents and the compilation of patent maps. An instrument for the composition of patent maps is the Multi-Dimensional Scaling (MDS) [48-51]. It can be used among others to display search results for patent analysis, keywords and bibliographical criteria such as IPC-, USPC-classification as well as for citing information. Tijssen [48] shows the operationalisation of bibliographic data through different varieties of MDS that can also be assigned to patent data.

The combination of the text-mining tool Knowledgist™ 2.5 and the developed data-mining tool PIA provides a promising instrument to deal with patent information overload. It forms a novel approach to gather the relevant information of patents. A multivariant method such as MDS then assembles patent maps which offer a quick overview about the similarities of the patent contents. Problem-oriented patent researches on the basis of semantics open up new possibilities in innovation and patent management. They support innovation management with information in particular for brainstorming [52], and they facilitate revelation of patent infringement [53], or even new approaches for Mergers & Acquisitions [54] as well as for inventor profiling [55]. They also offer new benchmarking approaches for patent management via SAO-cluster and enable compressions of relevant patent knowledge in SAO-structures. Within the scope of this paper we will describe how semantic analysis can be applied for the exploitation of bionic principles in patents.

4. Exploitation of bionic principles in patents

By using the semantic patent analysis above as a proper and promising application, the bionic ideas documented in patents are to be made accessible and visualized in semantic patent maps. The starting point for this investigation is a multi-stage process, finally also generating computer-aided patent maps. The process includes five steps; Selection of patents; Extraction of semantic structures; Forming similarity matrices; Positioning; and Representation. These steps are described below.

4.1. Selection of patents

Since semantic analysis can only be done with English texts, the source of supply for patents was the public available database of the US patent office (USPTO). The USPTO published all issued patents as a full-text document since 1976. Since bionic ideas were to be made accessible, the term „bionic“ was searched in the description part of all issued patents in the USPTO database. So e.g. between early 1977 and end of 2006 147 US patents were selected. Figure 2 shows the number of the issued patents over time whereas they are assembled in terms from the first term of 1977 till the second term of 2006. There can be found, that a considerable boost of up to 16 issued patents per term since 2000 has happened.

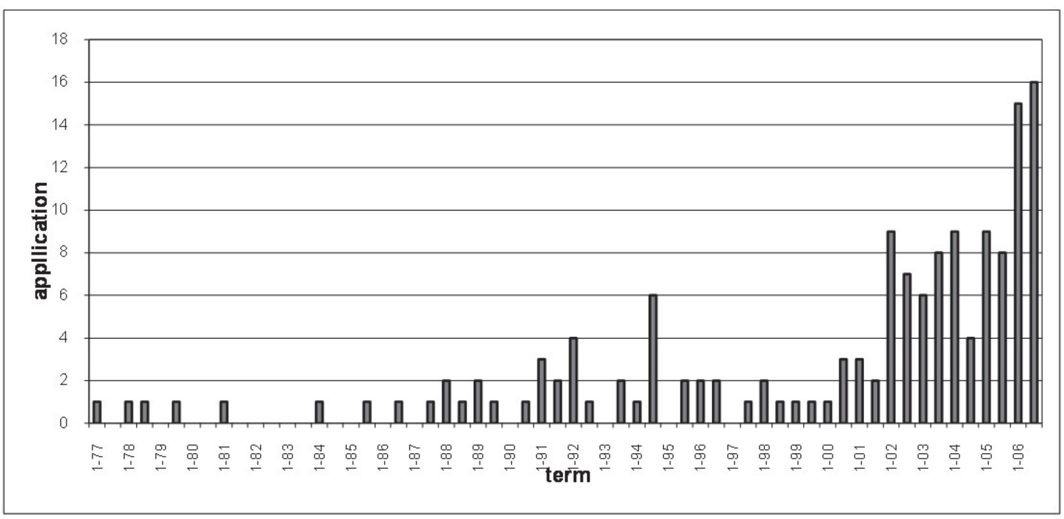

Figure 2: Number of issued US patents versus term. All these 147 patents comprises the item bionic in the description part of the patent text.

4.2. Extraction of semantic structures

After choosing the patents to be examined, in the first stage simple semantic structures are extracted from the patent texts. This can be done by means of a semantic processor (Natural Language Processor (NLP)) implemented in the software tool Knowledgist™ 2.5. This processor formulates the central message of the analysed documents through so-called Subject-Action-Object structures (SAO-structures). The action and related object constitute the particular task, and the subject is the solution to the task. A SAO structure is therefore also called a technical cause-effect relationship.

For this semantic analysis the SAO-structures were now extracted from the 147 chosen patents. With using the implemented standard filter of the Knowledgist™ 2.5 17.588 SAO-structures were found (10 SAO examples are shown by table 1). The quantities of SAO-structures within single patents cover a wide range (from 6 to 643), the median being in the vicinity of 119 SAO-structures per patent.

4.3. Forming similarity matrices

A matrix of similarity indicators is created by making statistical comparisons of the semantic structures of a large number of patents. An initial software prototype, called the Patent Information Analysis (PIA) tool, has already been implemented and creates the necessary similarity matrices from several patent pools of SAO structures. Additionally to the imported SAO-structures, bibliographic data like the IPC- or USPC-classification, the date of issue or the assignee are saved to a specific data set for reasons of organization but not involved in computing similarities. All information is stored inside a database which is accessible at any time. Each SAO-dataset can be compared with any other. Consequently, it is possible to compute similarity values for every single patent included in the dataset (for the development and examples of similarity values see [54. Similarity values can serve as input for various techniques of visualization.

The similarity value employed in this study is based on a patent-to-patent measurement, using a quotient, of which the numerator captures similar SAO-, AO- and S-structures and weighs them individually. The denominator represents the smallest number of SAO-structures within both examined patents.

4.4. Positioning

A specific variant of Multi-Dimensional Scaling (MDS) creates a positioning structure in n-dimensional space from the similarity matrix. (for a short introduction to multidimensional scaling see [56].

The method of MDS emerged in the 1990s and has become increasingly popular ever since. First studies were undertaken by [49, 50] and by [51]. Contrary to the approach proposed in this exposition, they used key words and their co-occurrence as well as bibliographic data for capturing similarities between patents.

Apart from MDS a number of other approaches to patent mapping have been developed. Recent methods [57-59] often include the use of neural networks or self-organizing mapping-techniques for the visualization of similarity data.

4.5. Representation

With the positioning data and other attributes of the patents, various patent maps can then be generated in order to display the results of the analysis. In our investigation the similarity matrices were visualized as patent maps by means of ordinal multidimensional scaling implemented in the SPSS-module PROXSCAL.

Figure 3 shows a patent map representing all 147 patents from 1977 to 2006. The analysis reveals that the vast amount of patents deals with medical applications. The patents on the left (triangle tagged dots) can be clustered to a group of medical applications, especially surgery. This group primarily contains patents assigned to USC Class 607. In contrast to this group are the patents in the central and upper part of the map. These patents are dedicated to inventions in the domain of prosthesis. In total, 41 patents belong to US Class 607 (SURGERY: LIGHT, THERMAL, AND ELECTRICAL APPLICATION). These are tagged with triangle dots. Further 20 patents belong to US Class 623 (PROSTHESIS (I.E., ARTIFICIAL BODY MEMBERS), PARTS THEREOF, OR AIDS AND ACCESSORIES THEREFOR), tagged with square dots. Any other patents (circular dots) belong to further US Classes (see below and tab. 2).

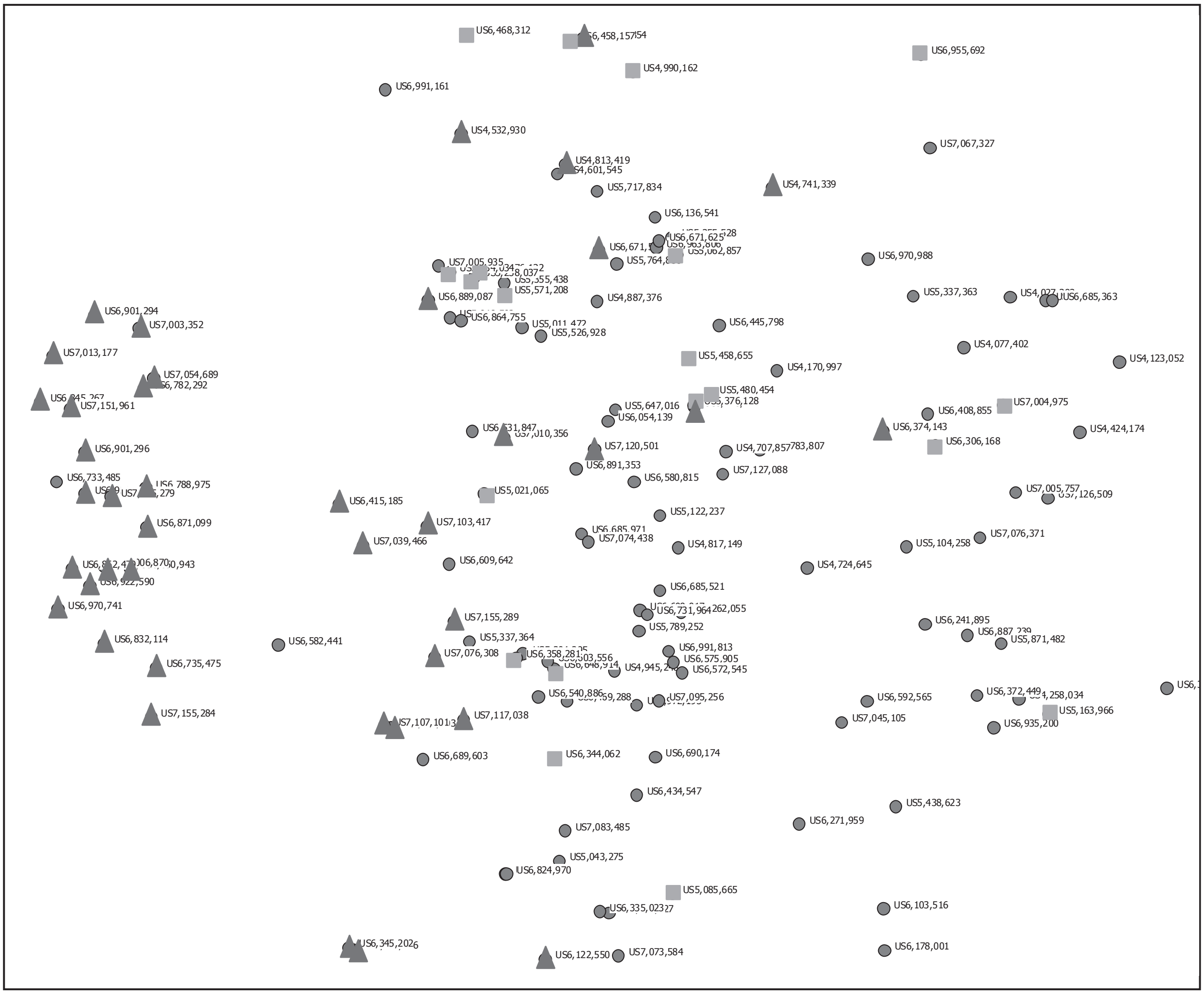

Fig. 2: Semantic patent map for bionic patents. N = 147, Stress = 0,196. The triangle tagged dots (41 patents) are patents of US Class 607 whereas square tagged dots (20 patents) are representing patents of US Class 623. The other circular tagged dots represent the further 86 patents. The size of the dots is not of any relevance.

Furthermore the USPC analysis shows in detail that most of the 147 selected patents are located in the area of medical applications (table 2). Table 2 only contains the USPC classes with more than two applications. The remaining applications are distributed over 9 (each two patents) and 27 (each one patent) classes. Thus alone 41 patents (corresponds to 27,9% of all patents) are concerned with the topic of applying light or analogous rays to the body or modifying the temperature of the body or applying electricity to the body.

number of patents	USPC class	
41	607	SURGERY: LIGHT, THERMAL, AND ELECTRICAL APPLICATION
20	623	PROSTHESIS (I.E., ARTIFICIAL BODY MEMBERS), PARTS THEREOF, OR AIDS AND ACCESSORIES THEREFOR
9	435	CHEMISTRY: MOLECULAR BIOLOGY AND MICROBIOLOGY
6	424	DRUG, BIO-AFFECTING AND BODY TREATING COMPOSITIONS
5	381	ELECTRICAL AUDIO SIGNAL PROCESSING SYSTEMS AND DEVICES
4	600	TYPEWRITING MACHINES
4	606	SURGERY
4	706	DATA PROCESSING: ARTIFICIAL INTELLIGENCE
3	382	IMAGE ANALYSIS
3	604	SURGERY
3	702	DATA PROCESSING: MEASURING, CALIBRATING, OR TESTING

Tab. 2: Allocation of the selected number of US patent applications to the USPC classes. The most issued patents are medical applications.

5. Summary

As the overall aim, the paper attempts to bridge the gap between the engineering-driven field of bionics, TRIZ and its different developments on the one hand and on the other, the technology-intensive area of patent analysis and specialized software support. Although research in all these domains is still quite disparate, recent progress in ICT enables an array of unique capabilities to be employed for linking theses domains and closing this gap. Using patent analysis – although not actually new in itself [60] – provides promising support and opens up windows for new applications, surely to the benefit of all groups involved in or affected both, by bionics and patent analysis, be they engineers, scientists, researchers, product developers, patent attorneys or organisations focused on patent analyses.

Patent analysis is a suitable method to identify how a certain field has developed over time, what are the main applications of particular technologies, and what are the characteristics of technologies in certain countries. An early patent analysis conducted in the early 1990s, however, reveals that information on current patent activities in bionics is quite difficult to be obtained [12]. The underlying reason was that conventional mechanisms like searching for key words did not seem to be a proper strategy because “bionic inventions” were often not marked as such. At that time, it was further likely that any publication analysis might have shown a similar limited result. As a young discipline with its scientific profile is just emerging such a phenomenon may not be surprising at all. Both, researchers and patent lawyers, probably might have choosen other key terms that were already established compared to terms with a merely young history like “bionics” or “bionic”.

Moreover, it is not quite clear whether bionic inventions are patentable to a certain degree, or at all. It is a requirement that something that needs to be protected by patents must be innovative, be it the task, solution, and application. Compared to conventional inventions, bionic inventions tend to be common “natural practice”, at least in parts, as by definition bionic inventions are based on models working in nature. Primarily it is the application that seems to be truly innovative. In order to avoid any misunderstandings and not prevent raising questions when patenting, researchers may likely not refer to any models working in nature. As a result, the terms “bionics” and “bionic” may be used only in a limited sense.

Compared to the early efforts more than ten years ago, however, the situation in patenting and the behaviour of researchers and in companies have changed substantially: In a number of industries such as semiconductors, software, biotechnology and pharmaceuticals established companies can only survive if they have a sufficient number of patents, e.g. for technology exchange [61, 62] as well as the industry-specific research by Beresford [63], Mehnert [64], Wood [65] and Ziedonis [66]. Furthermore, executives in many companies recognise that licensing can be used to cash in on intellectual property rights evidenced by patents. IBM, for example, increased its licence position from US$ 30 million in the early 1990s to about US$ 1.5 billion in the year 2000 [67]. And, last but not least, patents have become an increasingly decisive factor in corporate management with a positive impact on the companies’ success [68, 69].

The commonly used slogan “learning from nature to inspire human innovation” may be changed in this light to: “Using patent analysis to identify and map bionic solutions extracted from nature”. Resulting from a semantic patent analysis between 1977 and 2006, the patent map clearly shows that most bionic inventions are patented as medical applications in the area of surgery. Other fields of technological applications, however, apparently do not make use of bionic ideas for solving inventive problems. Hence, there is much room for improvements. Bionics provides a great potential for solving technical problems that needs to be exploit, e.g. perhaps to be carried out with the help of TRIZ.

One may just follow the famous example of Raoul Francé. 87 years ago, he was confronted with the task of inoculating soil evenly with micro organisms. He then tried various sprinklers and nebulizers but finally ended up with a poppy seed capsule as a suitable model. After realizing this, Francé got his ”new sprinkler“ patented in 1920 without any problem (German patent office, No. 723730). It was thus one of first examples of bionic patents in Germany.

Bionics is often announced as the field of research that systematically uncovers nature’s patents for the use for technological applications. Bearing this in mind, one may ask: How much are patents influenced by bionics? To what amount is a patent’s basis bionic? Perhaps, it may be helpful here to remember the words of Vincent [40] who reviewed literature in the field of bionics: “Tell someone that an idea comes from nature and you’re halfway toward selling it.“ However, learning from nature, though, is not a trivial enterprise of finding and copying “best practice” situations, very often in an attitude of “pick and mix”. It is even more complex to find out whether a patent may have its roots in bionics.

References

[1] Moehrle, M. G. (2005): What is TRIZ? From Conceptual Basics to a Framework for Research. *Creativity and Innovation Management*, 14(1), 3-13.

[2] Isenmann, Ralf (2001): Innovationsquelle Natur - Was wir von der Natur zur Ableitung von ökologischen Innovationen lernen können. *Technische Biologie und Bionik 5*. A. Wisser; W. Nachtigall (Hrsg.). Mainz: Akademie der Wissenschaften und der Literatur, 224-242.

[3] Bundesministerium für Bildung und Forschung (BMBF) (2005): *Innovationen aus der Natur. Förderkonzept Bionik*. Bonn, Berlin: BMBF.

[4] Kull, U.; Raum, E.; Reiner, R. (1995): *Evolution und Optimierung. Strategien in Natur und Technik*. Stuttgart: Hirzel.

[5] Zerbst, E.W. (1987): Bionik. Biologische Funktionsprinzipien und ihre technischen Anwendungen. Stuttgart: Teubner.

[6] Hill, B. (1999): Naturorientierte Lösungsfindung. Entwickeln und Konstruieren nach biologischen Vorbildern. Renningen-Malmsheim: Expert.

[7] Isenmann, R. (2003): Natur als Vorbild. Plädoyer für ein differenziertes und erweitertes Verständnis der Natur in der Ökonomie. Marburg. Metropolis.

[8] Kueppers, U.; Tributsch, H. (2002): *Verpacktes Leben – Verpackte Technik. Bionik der Verpackung*. Weinheim: Wiley-VCH.

[9] Lu, Y. (2004): Significance and progress of bionics. *Journal of Bionics Engineering* 1(1): 1-3.

[10] BIOKON (2006): *Patente aus der Natur. Bionik-Kongress in Bremen. 27.-28. Oktober 2006*. University of Applied Sciences Bremen.

[11] Schmitt, O.H. (1969): Some interesting and useful biomimetic transforms. Proceedings of the Third International Biophysics Congress. August 29-September 3, 1969. Boston, MA, 297.

[12] Verein Deutscher Ingenieure (VDI) (Ed.) (1993): *Analyse & Bewertung zukünftiger Technologien*. Technologie-Analyse Bionik im Auftrag des Bundesministeriums für Forschung und Technologie (BMFT). Düsseldorf: VDI.

[13] http://www.gtbb.org/

[14] http://www.biokon.net/index.shtml.en

[15] Bar-Cohen, Y. (Ed.) (2006): *Biomimetics. Biologically inspired technologies*. Boca Raton et al. Taylor & Francis.
[16] Benyus, J.M. (1998): *Biomimicry: Innovation inspired by nature*. New York: HarperCollins.
[17] http://www.biomimicry.net/indexbiomimicryexp.htm
[18] Nachtigall, W. (1974): *Phantasie der Schöpfung. Faszinierende Entdeckungen der Biologie und Biotechnik*. Hamburg: Hoffmann & Campe.
[19] Rosnay J de (1977): *Das Makroskop. Neues Weltverständnis durch Biologie, Ökologie und Kybernetik*. München: dtv
[20] Krause, H. (1984): *Natur – Vorbild der Technik*. Thun und Frankfurt am Main: Harri Deutsch.
[21] Vester, F. (1991): *Neuland des Denkens. Vom technokratischen zum kybernetischen Zeitalter*. München: dtv.
[22] Rechenberg, I. (1994): *Evolutionsstrategie ,94. Werkstatt Bionik und Evolutionstechnik*. Band 1. Stuttgart: Frommann-Holzboog.
[23] Vogel, S. (1998): *Cats' paws and catapults. Mechanical worlds of nature and people*. London: Penguin Books.
[24] Gleich, A. von (Ed.) (2001): *Bionik. Ökologische Technik nach dem Vorbild der Natur?* Stuttgart: Teubner.
[25] Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBFT) (1997): *Neue Materialien für Schlüsseltechnologien des 21. Jahrhunderts – MaTech*. Bonn: BMBFT.
[26] Bundesministerium für Bildung und Forschung (BMBF) (2004): *Nachhaltiges Wirtschaften. Innovationen aus der Umweltforschung.* Berlin: BMFT.
[27] Bundesministerium für Bildung und Forschung (BMBF) (2005): *Innovationen aus der Natur. Förderkonzept Bionik.* Berlin: BMFT.
[28] Boblan, I.; Banasch, R. (Eds.) (2004): *First International Industrial Conference Bionik 2004. April 22nd and 23rd, 2004 held attendant to the Hannover Messe, Hannover (Germany)*. Fortschritt-Berichte VDI. Reihe 15 Umwelttechnik. Düsseldorf: VDI.
[29] BIOKON (2006): *Innovationsmotor Natur. Bionik Industriekongress 2006*. Berlin: BIOKON.
[30] TU Darmstadt (2002): Bionik. Biologisch-technische Systeme. *Thema Forschung* 2/2002. Technische Universität Darnstadt.
[31] Malik, F. (2006): *Der Quantensprung im Top-Management. Mit Kybernetik, Systemik und Bio-Logik die Zukunft sichern*. Best of 1. International Bionik-Kongress für das Top-Management 9.-10. März 2006, Interlaken. Malik Management Zentrum St. Gallen.
[32] Isenmann, R. (1996): Natur als Vorbild? *Rundschreiben der Gesellschaft für Bionik und Technische Biologie* (GTBB) 18: 2-3.
[33] Isenmann, R. (2001): Innovationsquelle Natur - Was wir von der Natur zur Ableitung von ökologischen Innovationen lernen können. *Technische Biologie und Bionik 5*. A. Wisser; W. Nachtigall (Eds.). Mainz: Akademie der Wissenschaften und der Literatur, 224-242.
[34] Isenmann, R. (2003): Further efforts to clarify Industrial Ecology's hidden philosophy of nature. *Journal of Industrial Ecology* (JIE) 6(3/4): 27-48.
[35] Simonis, U.E. (1993): Von der Natur lernen? Über drei Bedingungen zukunftsfähiger Wirtschaftsentwicklung. *Natur als Vorbild. Was können wir von der Natur zur Lösung unserer Probleme lernen?* E. Zwierlein (Ed.). Idstein: Schulz-Kirchner: 115-133.
[36] Isenmann, R.; Hauff, M. von (Eds.) (2007): *Industrial Ecology. Mit Ökologie nachhaltig wirtschaften*. München: Elsevier.
[37] Becker, C.; Faber, M.; Hertel, K.; Manstetten, R. (2005): Maltus vs. Wordsworth: Perspectives on humankind, nature and economy. A contribution to the history and the foundations of ecological economics. *Ecological Economics* 53: 299-310.
[38] Levine, S.H. (2000): Products and ecolocical models. A population ecology perspective. *Journal of Industrial Ecology* 3(2/3): 47-62.
[39] Tilley, D. (2003): Industrial ecology and ecological engineering – opportunities for symbiosis. *Journal of Industrial Ecology* 7(2): 13-32.

[40] Vincent, JF.V. (2000): Deployable structures in nature: Potential for biomimicking. Proceedings of the I MECH E Part C. *Journal of Mechanical Engineering Science* 214(1), 2000-01-24: 1-10.
[41] Cuddington, K. (2001): The "balance of nature" metaphor and equilibrium in population ecology. *Biology and Philosophy* 16: 463-479.
[42] Haila, Y. (2000): Beyond the nature-culture dualism. *Biology and Philosophy* 15: 155-175.
[43] Zoglauer, T. (1994): Modellübertragungen als Mittel interdisziplinärer Forschung. *Technomorphe Organismuskonzepte. Modellübertragungen zwischen Biologie und Technik.* W. Maier; T. Zoglauer (Eds.). Stuttgart: Frommann-Holzboog, 12-24.
[44] Altschuller, G. S. (1998): *Erfinden – Wege zur Lösung technischer Probleme*. 2. Aufl. Cottbus: Planung und Innovation.
[45] Stauch, R. (2001) *Manuskript über Knowledgist*. Invention Machine germany GmbH, Ingolstadt.
[46] Tsourikov, V.M.; Batchilo, L.S.; Sovpel, I.V. (2000): US-Patent 6,167,370 (Dec. 26, 2000). Invention Machine Corporation. Priority: US09/321,804 May 27, 1999. Document semantic analysis/Selection with knowledge creativity capability utilizing subject-action-object (SAO) structures.
[47] Invention Machine (2002): Knowledgist-Broschüre. http://www.invention-machine.com/prodserv/knowledgist.cfm.
[48] Tijssen, R. J. W. (1992): *Cartography of science. Scientometric mapping with Multidimensional Scaling Methods*. Leiden: DSWO Press.
[49] Peters, H.P.F.; van Raan, A.F.J. (1993): Co-word-based science maps of chemical engineering. Part I: Representations by direct multidimensional scaling. *Research Policy*, 22(1), 23-45.
[50] Peters, H.P.F.; van Raan, A.F.J. (1993): Co-word-based science maps of chemical engineering. Part II: Representations by combined clustering and multidimensional scaling. *Research Policy*, 22(1), 47-71.
[51] Engelsman, E.C., van Raan, A.F.J. (1994): A patent-based cartography of technology. *Research Policy*, 23(1), 1-26.
[52] Walter, L.; Geritz, A.; Moehrle, M. G. (2003): Semantische Patentanalyse mit dem Knowledgist und PIA. Grundlagen – Beispiele – Kritik. *PATINFO 2003. Gewerbliche Schutzrechte für den Aufschwung in Europa. 25. Kolloquium über Patentinformation, Ilmenau, 19.-20.5.2003*; R. Schramm; H. Schwanbeck (Hrsg.). Ilmenau, 235-248.
[53] Bergmann, I.; Moehrle, M. G.; Walter, L.; Butzke, D.; Erdmann, V.A.; Fuerste, J.P. (2007): The Use of Semantic Maps for Recognition of Patent Infringements, Based on a Case Study in Biotechnology. *Zeitschrift für Betriebswirtschaft ZfB*, in press.
[54] Moehrle, M.G.; Geritz, A. (2007): Developing acquisition strategies based on patent maps. *Management of Technology: New Directions in Technology Management*. Sherif, M.H.; Khalil, T.M. (Eds.). Oxford, Amsterdam: Elsevier, pp. 19-29
[55] Moehrle, M. G.; Walter, L.; Geritz, A.; Müller, S. (2005): Patent-based inventor profiles as basis for human resource decisions in R&D. *R&D management* 35(5): 511-523.
[56] Borg, I., Groenen, P. (1997). *Modern multidimensional scaling: theory and applications.* New York et al.: Springer.
[57] Kohonen, T. (2001). *Self-Organizing Maps.* Berlin: Springer.
[58] Yoon, B.-U.; Yoon, C.-B.; Park, Y.-T. (2002): On the development and application of a self-organizing feature map-based patent map. *R&D Management*, 32(4), 291-300.
[59] Yoon, B., Park, Y. (2004): A text-mining-based network. Analytical tool for high-technology trend. *Journal of High Technology Management Research*, 15(1), 37-50.
[60] Cascini, G.; Russo, D. (2007): Computer-aided analysis of patents and seacrh for TRIZ contradictions. Int. J. Product Development, 4, 1/2: 52-67.
[61] Ernst, H. (2003): Patent information for strategic technology management. *World Patent Information,* 25(3): 233-242.
[62] Ernst, H.; Omland, N. (2003): Patentmanagement junger Technologieunternehmen. *Zeitschrift für Betriebswirtschaft,* Ergänzungsheft 2/2003: 95-113.
[63] Beresford, K. (2001): European Patents for Software, E-commerce and Business Model Inventions. *World Patent Information,* 23: 253-263.

[64] Mehnert, M. (2002): *Ermittlung, Bewertung und Verfolgung von Patentverletzungen. Eine betriebswirtschaftliche Untersuchung bei forschenden Pharmaunternehmen in der Bundesrepublik. Berlin*: www.dissertation.de.
[65] Wood, D. (2001): European Patents for Biotechnological Inventions – Past, Present and Future. *World Patent Information,* 23: 339-348.
[66] Ziedonis, R. H. (2003): Patent Litigation in the U.S. Semiconductor Industry. In: Cohen, W.M.; Merrill, S.A. (Eds.): *Patents in the Knowledge-based Economy:* 180-215. Washington D.C.: National Academies Press.
[67] Marsland, R. (2003): What Marshall Did Next. Intellectual Asset Management, 2: 15-18.
[68] Austin, D.H. (1993): An event-study approach to measuring innovative output: The case of biotechnology. *American Economic Review,* 83(2): 253-258.
[69] Hall, B.H., Jaffe, A.; Trajtenberg, M. (1999): *Market Value and Patent Citations: a first look.* CNRS Working Paper Nr. 99004, Paris.