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Biomimetics — Integrating problem- and function-oriented approaches applying the TRIZ method

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Foreword

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This document was prepared by Technical Committee ISO/TC 266, *Biomimetics*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Building on the success of the Millennium Development Goals (MDGs), the 2030 Agenda for Sustainable Development (the 2030 Agenda) is a set of international development goals to be met by 2030, adopted by the UN Sustainable Development Summit held in September 2015.

Sustainable Development Goals (SDGs) will be the impetus for change as the manufacturing and processing industries around the world are in need of new technology for the development of environmentally-friendly materials and processes. For that purpose, it is indispensable to realize low-energy and highly efficient manufacturing. Living things have a special technology for this aim.

In recent years, researchers have been expanding their work on biomimetic engineering (biomimetics), a field focused on introducing high efficiency and performance biofunctions into material design.[2-6] Biofunction is a development in engineering technology that elucidates the processes of activities related to the functions and life phenomena of animals, plants, and microorganisms, and makes them useful in real life. More and more articles on biomimetic engineering have been reported every year, and expectations that the industry will develop practical applications for such are likewise on the rise. Numerous well-known applications of biomimetics can be cited, e.g. self-cleaning paints based on lotus leaves, easy-to-peel-off tapes inspired by the microstructures in the soles of a gecko's foot, nonreflective films structured like the compound eyes of a moth, shark skin-patterned high-speed swimwear, automobile designs that incorporate ideas taken from a boxfish's skeleton, and labels that use the structural colours of the morpho butterfly. The ranks of companies whose interest in developing materials based on biomimetic engineering principles sparked by news reports about such developments likewise has been increasing.[2] There are more than 7,8 million species of living beings in the world, with an enormous number of distinct functions and behaviours. Whatever biofunction attracts our attention, it is unclear as to which ones will be useful toward developing innovative technologies and materials and lead to an optimal material design. In short, most engineers and researchers are challenged by their inability to focus on a single target owing to the excess of options. Thus, case-by-case material design is the mainstream in biomimetic engineering today. Only a portion of the limitless number of biofunctions are being put to use, and there are no effective means for extracting those technological elements that may be necessary. Furthermore, with ISO/TC 266 currently studying a variety of regulations regarding biomimetic engineering, there is demand for biomimetic products to be created that conform to international standards. According to ISO 18458, developing biomimetic biometric products requires they go through the following process: (1) identify issues with existing technologies and materials, (2) search for biofunctions that can resolve those issues, (3) extract and generalize the principles behind the biofunctions that have been discovered, and (4) create and optimize new technologies and materials. The question also arises of the best approach to take for identifying the functions among the 7,8 million living things said to exist and for optimizing them. This document introduces the database that will support the creation of biomimetics products according to ISO 18458.

Biomimetics — Integrating problem- and function-oriented approaches applying the TRIZ method

1 Scope

This document describes prototypes of a database for developing biomimetic products with innovative problem-solving methods (TRIZ). The database has a mechanism to obtain the idea of technical problem-solving using the problem- and function-oriented approaches. This document focuses on the use and value of the database, but also describes its design principles.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 23845, *Biomimetics — Ontology-Enhanced Thesaurus (OET) for biomimetics*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 23845 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
TRIZ
problem-solving, analysis and forecasting method derived from the study of patterns of invention in patent literature

Note 1 to entry: The theory of inventive problem-solving was invented by Genrich Altshuller, who while president of the Inventor's Association of Russia in 1946, discovered that the evolution of technical ideas followed predictable patterns.

3.2
problem-oriented approach
approach used to search for biological functions based on 40 principles using the *TRIZ* (3.1) matrix method

3.3
function-oriented approach
approach used to reach biomimetic solutions from the 40 *TRIZ* (3.1) principles by utilizing a combination of two elements, desired function and state

4 Current status of patents for biomimetics

The Japan Patent Office's *Survey Report on Technology Trends in Patent Applications* gives us a picture of current tendencies in regard to patents focused on biofunctions.[7] It can be inferred from a review of the data for products that are mainly related to biomimetics that at present the number of instances in which a patent has been commoditized is limited regardless of country or region. The main products can be broken down as belonging to one the following three broad categories.

a) Products related to molecules and materials. Examples include hydrophilic and hydrophobic materials (e.g. water-repellent paints, tile-related building materials, and water-repellent glass); structural coloration materials (e.g. chemical fibers); optical materials (e.g. antireflective film and displays); adhesive and gummed materials (e.g. adhesive tape, carpet tile, and cyclone vacuum cleaners); medical and biocompatible materials (e.g. injection needles and cosmetics); low-value resistance and low-friction materials (e.g. competition swimwear, fuselage paint for airplanes, and ship-coating materials); and antifouling materials (e.g. antifouling coating for ship bottoms).

b) Products meant to reduce the resistivity of a structure (e.g. cooling fans, washing machines, mixers, and the shape of the noses on bullet trains) or save weight (e.g. automobile wheels).

c) Products related to robots (e.g. robots patterned after dragonflies, elephant noses) or machine controls (e.g. sensors and software for controlling smart grids).

In Japan, numerous products related to the molecular and materials fields exist, e.g. hydrophilic and hydrophobic materials, optical materials, and adhesive and gummed materials. In the US and Europe, in contrast, more products in the machine field are encountered. Much work was once being done in Japan in the areas of biomimetic chemistry and robotics, and it was a leader in molecular scale biomimetics. However, researchers and engineers have not been able to keep pace with the new currents that emerged in material-related biomimetics in this century. Broadly speaking, this is because in Japan collaborations between different fields such as biology and engineering never took place owing to preconceptions in Japanese research and academic settings about interdisciplinary interactions. R. Kosaka et al. reviewed and analysed the latest trends related to biomimetics and innovations. It is followed by the comparative analysis of biomimetics-related patents versus the number of related scientific articles in Japan, the USA and European contexts. From the analysis, it is pointed out that the trends of research and patents are predominantly correlated in the USA and Europe. Japan has a relatively small number of patents and articles but has comparatively more activity in patent applications than in article publications.[8,9] Additionally, it is believed that the materials field will become the primary destination for application of biomimetics. If more products are to be brought to market in these areas, it will be necessary to develop even more technologies in the area of microstructure fabrication techniques in order to reduce manufacturing costs and improve durability. Furthermore, if the biomimetics market is to expand, would-be producers will need to adopt a “biomimetic” way of thinking in the control and processing fields. In particular, observers have highlighted the importance of autonomous distributed control systems, and the expectations of people involved in the field for advances in the development and practical application of such systems are high.

These reports concluded that biomimetics is applied to technical fields completely different from molecules/materials, structures, machines, and processes, and its application industry is extremely wide. In order to match with applied industries, it is necessary to overcome existing technical and industrial barriers. Therefore, it can be said that a biomimetics database that links knowledge from different technical fields and applied industries is essential.

5 Theory of database

5.1 TRIZ

There are a variety of approaches to solving engineering problems. Researchers and engineers have found success in wielding such approaches as a strengths, weaknesses, opportunities, and threats (SWOT) analysis, which applies a business framework to the problem; "logic" (or "issue") trees; Osborn's checklist; mind maps; quality control methodology; and the Taguchi method. Among these methods is one that has been applied in a variety of fields since 1990 as a means for generating ideas for material design in mechanical engineering. This is the Theory of Inventive Problem Solving, usually known by its Russian acronym TRIZ (Teoriya Resheniya Izobreatatelskikh Zadach, Теориярешенияизобретательскихзадач). TRIZ was developed by Genrikh Saulovich Altshuller (1926-1998), who worked as a clerk in a Russian patent office.[10-14] Altshuller came up with TRIZ as a set of "principles for performing creative problem solving" that applied a system to the regularities he uncovered in his examinations of some 1,5 million patents. The distinguishing feature of this method is that it presents a set of rules and principles for solving issues in engineering technology. The main feature of the TRIZ method is that its principles and the principles for solving engineering technology are presented, and by patterning the problem that needs to be solved, hints for problem solving are obtained regardless of research field. There are several usages such as (1) principle, (2) prediction, and (3) effects.

40 principles for problem-solving is one of the methods in category (1) principle in TRIZ, a technique to settle a problem from an invention principle of 40 by an inconsistent matrix way. The merit of the TRIZ method is that it presents a set of rules and principles for solving issues in engineering technology. It does this by looking for the patterns in the problems for which solutions are being sought, thus making it possible to get ideas about how to solve those problems regardless of the field of research. There is any number of ways to apply it based for example on principles, predictions, or effects. Here, we will focus on problem solving methods that make effective use of the 40 problem-solving principles the theory proposes. The principle-based approach entails taking the physical characteristics spanning the 39 parameters shown below and using them to create a 39-by-39 matrix comprising "parameters wish to improve" and "problems that will arise when improvement is made". The goal is to resolve the technological contradictions represented by the intersections between those parameters an inventor seeks to improve and those parameters that will change for the worse.

The 39 features of Altshuller's contradiction matrix:

(1) Weight of moving object (2) Weight of stationary object (3) Length of moving object (4) Length of stationary object (5) Area of moving object (6) Area of stationary object (7) Volume of moving object (8) Volume of stationary object (9) Speed (10) Force (11) Tension or pressure (12) Shape (13) Stability of composition (14) Strength (15) Time of action by a moving object (16) Time of action by a stationary object (17) Temperature (18) Brightness (19) Energy spent by a moving object (20) Energy by a stationary object (21) Power (22) Loss of Energy (23) Loss of substance (24) Loss of Information (25) Loss of Time (26) amount of substance (27) Reliability (28) Measurement accuracy (29) Manufacturing precision (30) Harmful factors acting on an object from outside (31) Harmful factors developed by an object (32) Manufacturability (33) Convenience of use (34) Repairability (35) Adaptability (36) Complexity of device (37) Complexity of control (38) Level of automation (39) Capacity / Productivity.

The 40 problem-solving principles of TRIZ:

(1) Segmentation (2) Extraction (3) Local Quality (4) Asymmetry (5) Consolidation (6) Universality (7) Nesting (8) Counterweight (9) Prior Counteraction (10) Prior Action (11) Cushon in Advance (12) Equipotentiality (13) Do It in Reverse (14) Spheroidality (15) Dynamicity (16) Partial or Excessive Action (17) Transition Into a New Dimension (18) Mechanical Vibration (19) Periodic Action (20) Continuity of Useful Action (21) Rushing Through (22) Convert Harm Into Benefit (23) Feedback (24) Mediator (25) Self-service (26) Copying (27) Dispose (28) Replacement of Mechanical System (29) Pneumatic or Hydraulic Constructions (30) Flexible Membranes or Thin Films (31) Porous Material (32) Changing the Color (33) Homogeneity (34) Rejecting and Regenerating Parts (35) Transformation of Properties (36) Phase Transition (37) Thermal Expansion (38) Accelerated Oxidation (39) Inert Environment (40) Composite Materials.

This Russian technology has been systematized by researchers around the world, including Dr. Darrel Mann and Dr. Nakagawa,[15] and has been developed using engineers, and many databases and software have been developed in each country. In addition, at present, TRIZ data collections from all over the world are linked, and an environment is in place where TRIZ industrial patents can be created from various sites. In Japan, Mitsubishi Research Institute spread TRIZ software to the world in 1997, and many companies are using TRIZ for engineering purposes. The Japan TRIZ Council was established in 2005, and the Japan TRIZ Association was established in 2007 (http://www.triz-japan.org/). At the TRIZ annual symposium of this association, development examples at many Japanese companies were reported.

5.2 Bio-TRIZ method

Engineers would like to add the functions in case of materials design for superior performance, but living creatures keep the principle to sacrifice something to get new functions as evolution. This optimization concept is called trade-off. Trade-off is a situational decision that involves diminishing or losing one quality, quantity or property of a set or design in return for gains in other aspects. The TRIZ method is a category of problem-solving using trade-off. Organisms evolve in response to changes in the environment by repeating trade-offs and acquiring new functions. By incorporating this mechanism into TRIZ, we can expect the development of products that incorporate a highly functional and highly efficient biological mechanism.[15] Bio-TRIZ is a new concept developed by Olga and Nikolaj Bogatyrev, designed to solve technical problems to bring high efficiency bio-functions found in nature into TRIZ's 40 problem-solving principles.[16] For example, in metallurgical and mechanical engineering, to open pores in a material means reducing its strength. However, living things create sophisticated structures that prevent cracks from forming when they open pores. This maintains the strength of a material while simultaneously saving weight. Biofunctions in this way are a significant source for patentable new technologies. They imply ideas for the development of next generation materials and can also be expected to do much in the area of education in new engineering design. Developing next-generation materials demands that their creators consider such factors as harmonizing with nature, environmental friendliness, and the use of biomass.

5.3 Biomimetics-integrating problem- and function-oriented approaches applying TRIZ

The database comprises carefully selected information, stored in files categorized into the 40 TRIZ problem-solving principles, about living things that can be used for establishing patents according to ISO 18458. The user can get ideas for efficiently developing biomimetic products in a short period of time, therefore, by optimizing the biofunctions the base presents by the problem-oriented approach and function-oriented approach. Furthermore, the data contained can also contribute to product development based on existing work since the user can also view an inventory of biomimetic products related to the SDGs.

6 Structure of biomimetics-integrating problem-and function-oriented approaches applying TRIZ

6.1 Problem-oriented approach — Search from technical contradiction matrix

There is demand for biomimetic products to be created that conform to international standards. According to ISO 18458, this database can provide novel idea to develop biomimetic products according (see Figure 1).

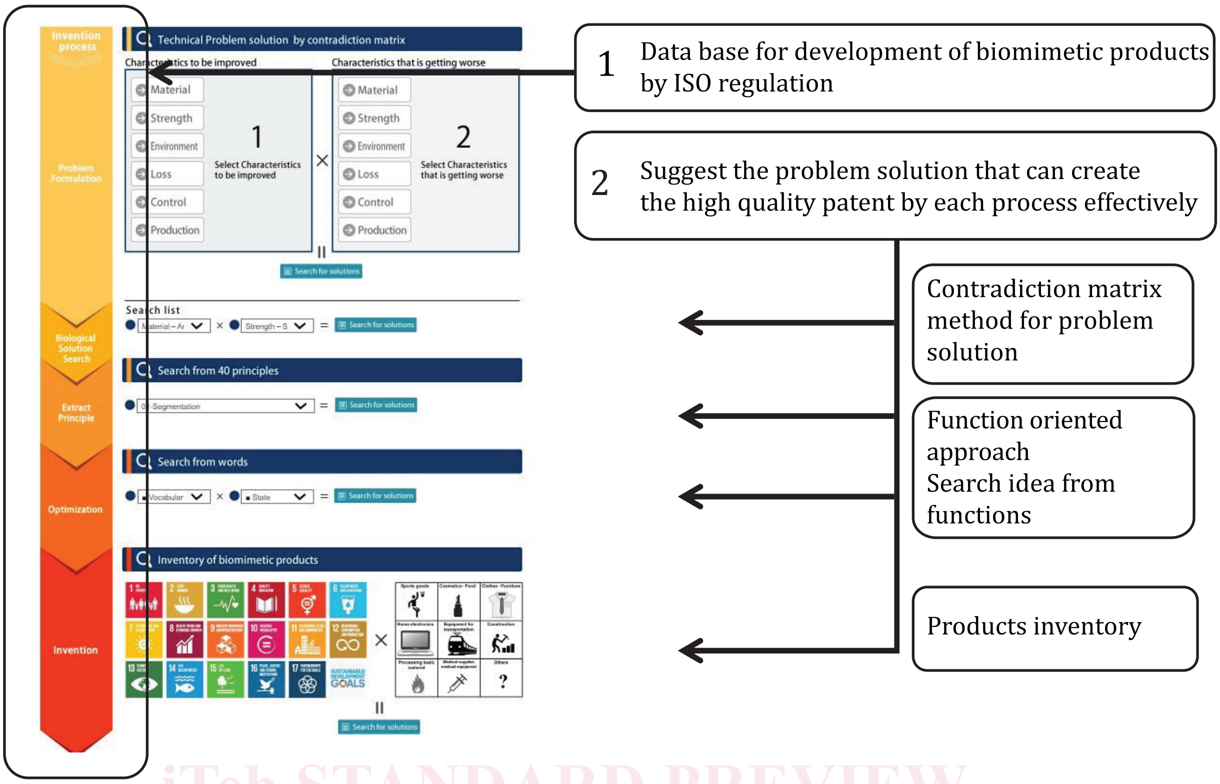

Figure 1 — Outline of database

The strength of this database lies in the fact that when the user queries it over technological contradictions, i.e. the problem of improving one parameter having a negative impact on another, it has the framework in place to automatically display any number of bio-functions that can suggest a solution as it runs through the four processes shown earlier (Figure 2 and Figure 3). The database comprises carefully selected information stored in files categorized into the 40 TRIZ problem-solving principles about living things that can be used for creating patents. This database can contribute to decision-making in the creation of biomimetic products. By merely condensing the technological problems which engineers face and putting them into a contradictions matrix, our database can supply the problem-solving principles that would seem appropriate for resolving those issues and furthermore will search out bio-functions for the user. The user can get ideas for efficiently developing biomimetic products in a short period of time by optimizing the bio-functions from this database. Furthermore, the data contained can also contribute to product development based on existing work since the user can also view an inventory of biomimetic products.

