CEAI, Vol.13, No.2, pp. 81-86, 2011 Printed in Romania

# Biological System Analysis in Bioinspired Conceptual Design (BICD) for Bioinspired Robots

**Aylin Konez Eroğlu*. Zühal Erden*.**
**Abdulkadir Erden***

** Department of Mechatronics Engineering, ATILIM University, Incek, Ankara, Turkey (Tel: +90-312-586-8306; e-mail: akonez@atilim.edu.tr).*

**Abstract:** Bioinspired design (BID) provides a systematic way for bioinspired applications. Although several BID approaches as well as some tools and databases are available in the literature, the studies on BID are still challenging for designers and/or engineers because of limitations of current BID approaches. There are mainly two directions related with these limitations. One of them is the representation of knowledge on biological systems and the second is the problem of transforming this knowledge into engineering domain. These limitations expose two questions; firstly, "What knowledge is required to describe biological systems?" and "How this knowledge is represented?" and secondly, "How this knowledge is transformed into the engineering domain?". This paper presents a study which aims to answer the first question about knowledge required to represent biological systems. This knowledge is obtained during "Analysis of Biological Systems" stage of a new suggested bioinspired conceptual design (BICD) procedure.

*Keywords:* bioinspired design, knowledge of biological systems, biological system analysis.

## 1. INTRODUCTION

The concept of "Bioinspired" refers to a transformation from biological domain to engineering domain. It is known that more reliable, efficient, and robust structures, materials, and processes can be developed by using bioinspired approach. Bioinspired design (BID) needs a systematic method for transformation and it uses analogical reasoning approach in which the source domain is the biological domain while the target domain is engineering (Mak and Shu, 2004a; 2004b; Wilson, 2008; Nelson et al., 2009; Helms et al., 2009; Tsujimoto et al., 2008).

Although several BID models are available in the literature, most of them have some limitations, especially in representing knowledge about biological systems and in translating this knowledge from biological domain to engineering domain (Wilson, 2008; Sartori et al., 2010). The limitations and possible solution ways lead the authors of this paper to investigate a systematic BID model. BID can be represented as a branch of engineering design and the main difference is observed in the conceptual design phase. Bioinspired conceptual design (BICD) process is suggested to contribute systematic BID (Konez Eroğlu et al., 2011a; 2011b). This paper presents a study on the "analysis of biological systems" stage of the new BICD process. The main aim of this paper is to clarify scope of knowledge required to represent a biological system.

The paper is organized as follows: Section 2 introduces existing literature on the bioinspired design (BID) models and suggests a systematic bioinspired conceptual design (BICD). Section 3 explains "analysis of biological systems" stage of the BICD. This section addresses knowledge required to represent biological systems. Finally, Section 4 summarizes and discusses the studies in this paper.

## 2. BID MODELS AND SUGGESTED BICD PROCEDURE

Wilson (2008) stated that "Bioinspired design is the transfer of design strategies used in the natural domain to the engineering domain. Leveraging biological technologies in the engineering domain can lead to many technological innovations and novel products." In other words, the BID provides guideposts for engineering creativity (Fleischer, 1999). A cross-over link between biological systems and engineering systems (The Natural Edge Project, 2008) has led to new and useful products and technologies (Vincent and Mann, 2002) and some of them have been patented (Anon, 2007). The studies on BID models continue and some current studies are given in the next section of the paper.

### *2.1 Current BID Models*

There are two approaches in BID studies with respect to starting point of the design; problem-based BID (PB-BID) and solution-based BID (SB-BID). PB-BID starts with an engineering problem in engineering domain whereas SB-BID begins with a biological system in biology domain. Some examples of these studies are tabulated in Table 1.

**Table 1. Some examples of BID models**

| BID | Author(s) | BID steps | Domains of Steps |
|---|---|---|---|
| PB | Helms, Vattam, and Goel, | problem definition<br>reframe the problem (biologizing)<br>biological solution search | Engineering<br>Engineering-Biology<br>Biology |

| | | | |
|---|---|---|---|
| | (2009) | define the biological solution | Biology |
| | | principle extraction | Biology-Engineering |
| | | principle application | Engineering |
| | The Natural Edge Project, (2008) | identify the real challenge | Engineering |
| | | translate the challenge into biology language–'Biologise' the question | Engineering-Biology |
| | | define the habitat parameters/conditions | Biology |
| | | re-ask 'How does nature do that function here, in these conditions?' | Biology |
| | | find the best natural models (literal and metaphorical) | Biology |
| | | mimic the natural model as form, process, and ecosystem | Biology-Engineering |
| | | evaluate the solution – nature as measure | Engineering |
| | | pay respect to the Inspiration | Engineering |
| | Biomimicry Guild, (2009) | distill (distill the design function) | Engineering |
| | | translate (translate to biology) | Engineering-Biology |
| | | discover (discover natural models) | Biology |
| | | emulate (emulate natures strategies) | Biology-Engineering |
| | | evaluate (evaluate your design against life's principles) | Engineering |
| SB | Vakili and Shu, (2001) | select initial information source of biological phenomena | Biology |
| | | identify of synonyms for engineering functional keywords | Biology |
| | | identify of suitable bridge between engineering functional keywords and synonyms and biological phenomena | Biology-Engineering |
| | | search for keywords and synonyms in bridge | Biology-Engineering |
| | | identify and find more detail on relevant biological phenomena | Biology |
| | Anon, (2007) | identify a biological system | Biology |
| | | analyze biomechanics, functional morphology and anatomy | Biology |
| | | understand the principles | Biology |
| | | abstract from the biological model | Biology-Engineering |
| | | implement technology through prototyping and testing | Engineering |
| | Helms, Vattam, and Goel, (2009) | identify of a biological solution | Biology |
| | | define of the biological solution | Biology |
| | | extract of a principle | Biology |
| | | reframe the solution | Biology |
| | | search a problem | Biology-Engineering |
| | | define of the problem | Engineering |
| | | apply of the principle | Engineering |

Table 1 shows that the common steps of PB-BID are "problem definition", "biological system selection", "biological system representation", and "implementation of the representation in engineering domain". Similarly, the common steps of SB-BID are "biological system selection", "biological system representation", and "implementation of the representation in engineering domain". These models have some limitations, such as lack of mapping between biological domain and engineering domain and lack of clarity for the representation of biological systems.

Some databases (Wilson, 2008; Sartori et al., 2010; AskNature, 2010; Vincent and Mann, 2002) are available and they are used to provide translation from biological domain to engineering domain or vice versa. However, most of them do not translate knowledge about biological systems to be used for engineering design. A new BICD procedure is proposed to eliminate the limitations of current BID studies and it is summarized in the following section.

*2.2 The BICD Procedure*

Four phases of engineering design in Pahl et al. (2007) are discussed for a BID. These are "planning and task clarification", "conceptual design", "embodiment design", and "detail design". Conceptual design in BID is different than that of a well-known engineering design process although the other phases are similar. Thus, a BID model is developed as Bioinspired Conceptual Design (BICD) and the other phases are implemented on BID. A BICD procedure was established by combining analogical reasoning between engineering and biological domains, and phases of engineering design. Representation of BICD phases for both PB-BICD and SB-BICD are demonstrated in Fig. 1. This representation shows that PB-BICD has an additional phase, "establish functions and behavioral model" which is a well-known design phase like the other engineering domain stages (Pahl et al., 2007). The other phases are the same for these two approaches.

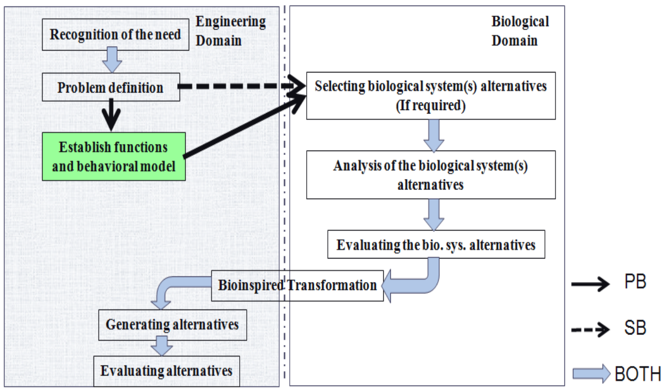


Fig. 1. PB-BICD and SB-BICD phases.

During the phase, "selecting biological system alternatives" keywords of the engineering domain are used to select biological system alternatives for each sub-task or sub-function. Available databases, such as AskNature (AskNature, 2010) or IdeaInspire (Sartori et al., 2010) can be used to find candidate biological systems. Then, during the phase "analysis of biological system(s) alternatives" each biological system alternative is analyzed to answer questions, such as, "What it does?" and "How it does?". Then, the available biological systems and their combinations are evaluated during the "evaluating biological system alternatives" phase using an appropriate engineering evaluation tool.

"Bioinspired transformation" phase provides a link between biological domain and engineering domain. This phase is required to systematically transform knowledge about a selected combination of biological systems from the biological domain into the engineering domain. Guidelines for the transformation phase should also be based on the understanding of what is transferred (Sartori et al., 2010). Details of the BICD phases are presented in (Konez Eroğlu et al., 2011a; 2011b).

There exist ambiguous points of the current BID studies; such as, knowledge required to represent a biological system and transformation of this knowledge into the engineering domain. It means that "analysis of biological systems" and "bioinspired transformation" require further studies. This paper is focused on the study of required knowledge which is obtained during the analysis. Next section discusses this phase from the view of required knowledge of biological systems.

## 3. ANALYSIS OF BIOLOGICAL SYSTEMS

Sartori et al. (2010) states that "It is possible to envisage a much broader use of structures and processes abstracted from nature in solving technical problems, when engineers have better access to existing biological knowledge...". In addition, Sartori et al. (2010) claims that "Even well-known biological solution can trigger innovative solutions in engineering if the knowledge is available at the right time and in the right form, a common language with which the functionality of both biological and engineered systems could be expressed.". It is known that analysis of biological systems is used to collect "correct" knowledge which should be translated from biological domain to engineering domain. Thus, an important question arises; "What is the required knowledge which represents biological systems?". In order to answer this question, two approaches are followed in this study. Firstly, biorobot definition is discussed, so that requirements of biorobots inspired from biological systems are emphasized. Secondly, existing case studies on biorobots are studied to collect properties of biological systems which are used to inspire.

The suggested BICD process is developed to provide design concepts of bioinspired robots, *biorobots*. Thus, before discussing the analysis step for biological systems, it is better to identify biorobots and required knowledge. There are several definitions for biorobots in the literature (Webb and Consi, 2001; Bar-Cohen, 2006; Meyer and Guillot, 2008). Bioinspired robots can be defined briefly as follows;

Biorobots, biologically inspired (bioinspired) robots or biomimetic robots, emulate the functions and performance of biological systems, look like inspiration model and behave similar to the original model. Biorobots can be decomposed under sensoric, motoric and cognitive sub-systems.

This definition is structured in a semantic network representation shown in Fig. 2. It should be noted that the purpose here is to use a semantic net as a well-known technique for the representation of relationships between concepts, rather than to search for the most efficient representation scheme.

Fig. 2 shows that a biorobot, as a machine, includes sensoric, motoric, and cognitive sub-systems in the engineering domain. In addition, the biorobot has visual appearance, behavior, and function and performance features which should be obtained from biological systems.

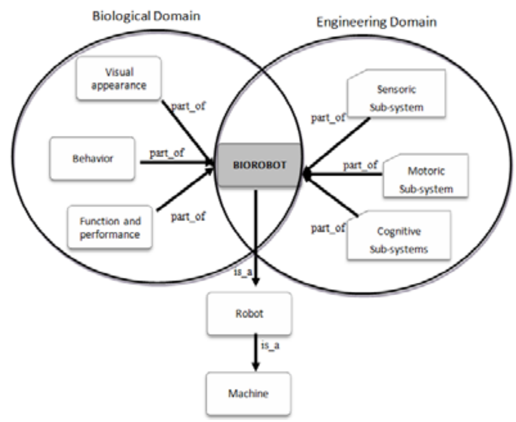


Fig. 2. A semantic network representation of a biorobot.

Similarly, to find "correct" knowledge of biological systems, the related literature on bioinspired robot case studies is investigated. The major consideration in the literature is to determine which aspects of the known biology should be included in the robot model (Webb and Consi, 2001). There are various ideas about the required knowledge and some of them are tabulated in Table 2.

**Table 2. Examples of different knowledge on biological systems collected from different case studies.**

| Reference | Knowledge about | Study on |
|---|---|---|
| Wiebe, (2009) | Ecology<br>Morphology<br>Anatomy<br>Physiology | Dynamic building |
| Eduardo et. al., (2008) | Biomechanical architecture<br>Sensory cognitive system | Human hand |
| Hu et. al., (2009) | Function and performance (kinematic modeling) | Fish fins |
| Laksanacharoen et al., (2000) | Morphology<br>Locomotion behavior | Walking and jumping of a cricket |
| Wang et. al., (2008) | Morphology<br>Jumping movement (kinematic data) | Jumping of a frog |
| Menon et. al., (2009) | Morphology<br>Mechanical structure | Campanifer sensilla of insects |
| Sitorus et. al., (2009) | Locomotion system (Function)<br>Anatomy Morphology | Fish fins locomotion |

Table 2 shows that knowledge used for transformation from biological domain to engineering domain can be investigated under the following category terms;

- Anatomy
- Behavior
- Biomechanical architecture
- Ecology
- Function
- Mechanical structure
- Morphology
- Physiology
- Sensory cognitive system

These terms are defined in Appendix A as they are used by the related literature (Marieb and Hoehn, 2006; Barnard, 2004; Erden et.al., 2008; Robertson et al., 2004; Either and Simmons, 2007; Wilson, 2008; Pahl et al., 2007; Söylemez, 2009; Matro, 2009; Webb and Consi, 2001). A semantic network representation of these terms is constructed using their definitions and it is given in Figure 3 in Appendix B.

This network shows that motion and forces are related with the function, which is a relationship between input/output of energy, material, and information to perform a task. Form and structure are parts of morphology, which includes anatomy of a biological system. Behavior of a biological system is affected by changes in the environment and behavior can implement different functions (Kitamura et al., 2006). Therefore, the triplet composed of "function", "morphology", and "behavior" can be used to represent a biological system, since all other features are in semantic relation with the elements of this triplet.

## 4. SUMMARY AND DISCUSSION

This paper presents an ongoing study on the "analysis of biological systems" phase of the bioinspired conceptual design (BICD) procedure. The aim of this paper is to determine the type of knowledge to be extracted during the analysis of biological systems. This knowledge, then, will be used for the "bioinspired transformation" phase. In this study, two approaches are used to represent characteristic knowledge of biological systems. These approaches are the following;

Development of a semantic network representation for bioinspired robot (biorobot) definition: The requirements using biorobot definitions in the literature were determined. A semantic network representation was developed for the biorobot definition. The representation shows that "form", "function", and "behavior" should be inspired from biological systems to design biorobots.

Development of a semantic network representation of biological systems using some case studies for biorobots in the literature: Several case studies were discussed and collected properties of biological systems were listed. After discussion on definitions of these terms, a semantic network representation was built. The network demonstrated that knowledge about "function", "morphology", and "behavior" can provide the representation of biological systems.

As a result, the study on analysis of biological systems step show that knowledge on function, morphology, and behavior of biological systems is required to represent a biological system. To obtain this knowledge two methods are prominence. The first method is to use literature survey and/or to consult biologists. Observation and measurement by using some technology, such as high speed camera, is the second method for analysis of biological systems.

Future work of this ongoing study includes refinement of the semantic net representation and working on various case studies on available biological systems using a high speed camera to extract the required knowledge.

## ACKNOWLEDGMENT

Authors greatly acknowledge the support of TUBITAK (The Scientific and Technological Research Council of Turkey), under the project "Development of biomimetic design methodology with reverse engineering in cognitive recognition and control of biomimetic robots" (TUBITAK 109M379). This is a joint project between Department of Mechatronics Engineering, ATILIM University, Turkey and University of Craiova, Romania.

## REFERENCES

Anon. (2007). *Biomimetics: strategies for product design inspired by nature- a mission to the Netherlands and Germany*. Report of a DTI Global Watch Mission, January

AskNature. (2010) www.asknature.org (Download Date: 02.03.2010)

Bar-Cohen, Y. (2006). *Biomimetics: biologically inspired technologies.* Taylor and Francis, United States of America.

Barnard, C. (2004). *Animal behavior: mechanism, development, function and evolution*. Pearson.

Biomimicry Guild. (2009). *Biomimicry: a tool for innovation.* http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html (Download Date: 02.03.2010)

Eduardo J., Puig, P., Rodriguez, N.E.N., and Cacarelli, M. (2008). A methodology for the design of robotic hands with multiple fingers. *International Journal of Advanced Robotic Systems*, vol. 5, No. 2 pp. 177-184.

Either, C.R. and Simmons, C.C. (2007). *Introductory biomechanics: from cells to organisms*. Cambridge.

Erden, M.S., Komoto, H., Beek, T.J.V, D'amelio, V., Echavarria, E., and Tomiyama, T. (2008). A review of function modeling: approaches and applications. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 22, pp. 147-169, USA.

Fleischer, J.G. (1999). *A method for biomimetic design of a cooperative mobile robot system to accomplish a foraging task.* Master Thesis, Colorado State University, Department of Mechanical Engineering.

Helms, M., Vattam, S.S., and Goel, A.K. (2009). Biologically inspired design: process and products. *Design Studies,* vol. 30 No. 5 pp. 606-622

Hu, T., Shen, L., Lin, L., and Xu, H. (2009). Biological inspirations, kinematics modeling, mechanism design and experiments on an undulating robotic fin inspired by Gymnarchus niloticus. *Mechanism and Machine Theory*, vol. 44 pp. 633-645.

Kitamura, Y., Koji, Y., and Mizoguchi, R. (2006). *An ontological model of device function: industrial deployment and lessons learned.* Applied Ontology, vol. 1, No. 3-4, pp. 237-262.

Konez Eroğlu, A., Erden, Z., and Erden, A. (2011a). Bioinspired conceptual design (BICD) approach for hybrid bioinspired robot design process. *IEEE International Conference on Mechatronics (ICM2011).* Istanbul, Turkey.

Konez Eroğlu, A., Erden, Z., and Erden, A. (2011b). Bioinspired conceptual design (BICD): conceptual design of a grasshopper-like jumping mechanism as a case study. *The 18th International Conference on Engineering Design (ICED11).*Copenhagen, Denmark. (accepted).

Laksanacharoen, S., Pollack, A.J., Nelson, G.M., Quinn, R.D., and Ritzmann, R.E. (2000). Biomechanics and simulation of cricket for microrobot design. *IEEE International Conference on Robotics and Automation*, San Francisco, pp. 1088-1094

Mak, T.W. and Shu, L.H. (2004a). Abstraction of Biological Analogies for Design. *CIRP Annals - Manufacturing* Technology, Vol. 53, Issue 1, pp 117-120

Mak, T.W. and Shu, L.H. (2004b). Use of biological phenomena in design by analogy. *ASME 2004 Design Engineering Technical Conferences and Computers and Information in Engineering Conference (DETC '04),* September 28-October 2, USA, DETC2004/DTM-57303

Marieb, E.N. and Hoehn, K. (2006). *Human anatomy and physiology*. Benjamin Cummings, Sevent Edition.

Matro, R. (2009). *An anthology of structural morphology*. World Scientific.

Menon, C., Brodie, R., Clift, S., and Vincent, J.F.V. (2009). Concept design of strain sensors inspired by Campaniform Sensilla. *Acta Astronautica 64* .pp. 176-182.

Meyer, J.A. and Guillot, A. (2008). *Chapter 60: biologically inspired robots, part G: human-centered and life-like robotics.* Springer Handbook of Robotics

Nelson, B., Wilson, J., and Yen, J. (2009). A Study of Biologically-Inspired Design as a Context for Enhancing Student Innovation. *39th ASEE/IEEE Frontiers in Education Conference, October 18-21, San Antonio, TX*

Pahl, G., Beitz, W., Feldhusen, J., and Grote, K.H. (2007). *Engineering design: a systematic approach.* Springer, London.

Robertson, D.G.E., Caldwell, G.E., Hamill, J., Kamen, G., and Whittlesey, S.N. (2004). *Research methods in biomechanics.* Human Kinetics, United States of America.

Sartori, J., Pal, U., and Chakrabarti, A. (2010). A methodology for supporting "transfer" in biomimetic design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 24, pp. 483-505.

Sitorus, P.E., Nazaruddin, Y.Y., Leksono, E., and Budiyono, A. (2009). Design and implementation of paired pectoral fins locomotion of Labriform fish applied to a fish robot. *Journal of Bionic Engineering*, vol. 6pp. 37-45

Söylemez, E. (2009). *Mechanisms.* METU Press, Turkey.

The Natural Edge Project Engineering Sustainable Solutions Program. (2008). Unit 3 - Biomimicry/Green Chemistry; *Lecture 9: Biomimicry - Design Inspired by Nature.* http://www.naturaledgeproject.net/ESSPCLP-Principles_and_Practices_in_SD-Preliminaries3.aspx. (Download Date: 26.02.2010)

Tsujimoto, K., Miura, S., Tsumaya, A., Nagai, Y., Chakrabarti, A., and Taura, T. (2008). A Method for Creative Behavioral Design Based on Analogy and Blending from Natural Things. *ASME 2008 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, IDETC/CIE 2008*, USA.

Vakili V. and Shu, L.H. (2001). *Towards biomimetic concept generation*. ASME 2001 Design Engineering Technical Conferences Design Theory and Methodology (DETC'01), Pittsburgh, Pennsylvania, September 9-12

Vincent, J.F.V. and Mann, D.L. (2002). Systematic technology transfer from biology to engineering. *Phil. Trans. R. Soc*. Lond. A 360, pp. 159-173.

Wang, M., Zang, X., Fan, J., and Zhao, J. (2008). Biological jumping mechanism analysis and modeling for frog robot. *Journal of Bionic Engineering* 5. pp.181-188

Webb, B. and Consi, T.R. (2001). *Biorobotics: methods and applications.*The MIT Press, Canada.

Wiebe, K. R. (2009). *Biomimetic design of the building envelope: biological climate adaptations and thermal controls in the sonoran desert*. Master Thesis, University of Southern California, Faculty of the School of Architecture.

Wilson, J.O. (2008). *A systematic approach to bio-inspired conceptual design.* Ph.D. Thesis, Mechanical Engineering Georgia Institute of Technology, USA.

## Appendix A. GLOSSARY

**Anatomy** is the branch of morphology and studies the structure of body parts and their relationships.

**Behavior**, which can implement different functions, is a sequential change of states over time with respect to change in the internal state of the body or in the environment.

**Biomechanics** is a science that study of forces interacting with living systems.

A **component** is a part of a system.

**Ecology** refers a relationship between biological systems and their environment.

**Form** refers to visual appearance.

A **function**, performing tasks, includes a relationship between input and output of energy, material, and information.

A **mechanism**, performing some functions, is a part of a machine including components.

**Morphology** is a science dealing with the form and structure of biological systems without consideration of function.

**Physiology** is a science concerning the function of biological systems.

**States** are structures that change in a short time.

A **structure** is an internal configuration of a system in which the components of a whole are assembled

Appendix B. A SEMANTIC NETWORK REPRESENTATION OF CONCEPTS USED IN CASE STUDIES OF BIOROBOTS

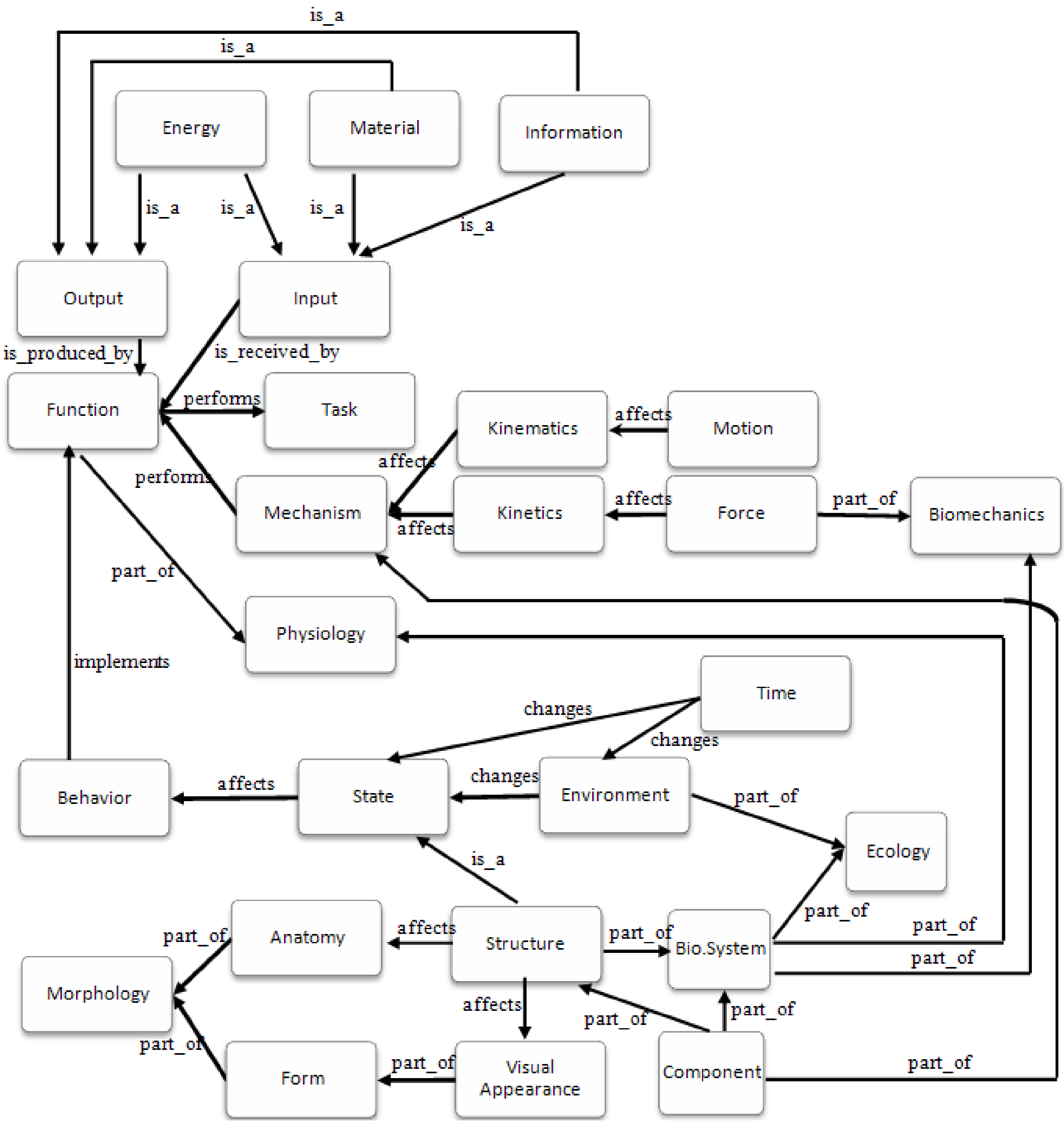


Fig. 3 A semantic network representation of concepts used in case studies on biorobot