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Industrial Engineering Journal

Transilvania University of Brasov, Romania

Vol. 14 (2013), No. 4(40) **ISSN 1582 - 0246**

ICEEMS 2013
7th International Conference
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November 2013

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Vol. 14, no. 4(40), November, 2013

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International Conference on Economic Engineering and Manufacturing Systems
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PRINCIPLES AND STAGES OF NEW GRIPPER SYSTEMS DEVELOPMENT

Doina NEGREA (ȚÂRLIMAN), Tudor DEACONESCU, Andrea DEACONESCU
Transilvania University of Braşov, Romania

Abstract. The paper presents the stages of developing new, light, eco-friendly and bionic gripper systems. Gripping is achieved by means of original, selfadaptive, bio-inspired systems, with a pneumatic muscle as motion generator. The method underlying the development of these new gripping systems is based on the creation of concepts by analogy, an instrument aimed at widening the inspiration horizon in designing by using models from nature.

Keywords: gripping system, pneumatic muscle, biomimetics

1. Introduction

Developing a new product is a process consisting of a defined set of tasks, steps and stages that describe the means by that an enterprise repeatedly transforms embryo ideas into marketable products or services. The development of a new product entails a logical sequence of stages, including, according to [1] the following:

- *Generation of ideas*, the initial innovative process continuing with the actual phases of the development process. The paper proposes *design-by-analogy* as a practical method of conceiving new constructive solutions;
- *Triage and selection of ideas*, aimed at identifying and selecting only solutions deemed viable. Within this stage multi-criteria analysis can be used to establish the optimum constructive solution for the new product;
- *Development of the concept*, that entails devising kinematic, geometrical and dynamic models;
- *Economic analysis*, for estimation of costs and establishing the profitability threshold;
- *Technical implementation* – the stage of practical achievement of the product;
- *Testing* of the new product;
- *Setting the price* and *marketing*of the new product.

Some of the above stages require iterations, while others, depending on the given situation can be eliminated.

In the vision of Gerhard Pahl and Wolfgang Beitz, the development of a new product includes a sequence of 4 phases [2]:

- *functional definition:* identifying the requirements to be satisfied by the new product;
- *concept definition:* identifying the physical principles to be used for ensuring the functional requirements;
- *morphological – physical definition:* identifying the necessary physical and organic elements for achieving the selected physical principles;
- *detailed definition:* describing the interactions between the components of the new product and how these are generated.

In a more recent edition of their book, Pahl and Beitz [3] present an updated procedure with a five-phase development process of technical products:

- *definition of the design topic*, when the product proposal and the list of requirements (specifications) are devised;
- *development of the principle solution (concept)*: establishing the structure of functions, the working principlesand combining concept variants. The result of this phase is a solution of principle (a concept);
- *development of the construction layout*: selecting preliminary configuration and form, selecting and computing materials and eventually improving the configuration. The result of this stage is a preliminary layout;
- *finalising the construction layout*: eliminating weaknesses, disturbance analysis, devising the preliminary list of components, the production and assembly documents. The result of this phase if the final layout;
- *preparation of production and operation documents*: devising manufacturing drawings of components, production, assembly, transport and operation instructions, etc. The result of this phase is the production documentation of the product.

Noticeably the German methodology proposed by Pahl and Beitz is focused on the designing process of the product.

The development of a new product entails, in its incipient phases, the existence of an innovative process of solution generation, each identifying new combinations of components, technologies and processes. At present several theories are known supporting the innovation process, one of them being the Theory of axiomatic design devised by professor Nam P. Suh from MIT (USA) [4]. Axiomatic design is a methodology of systems development deploying matrix based analysis such as to transform client needs into functional requirements, design parameters and process variables.

Another theory utilized in the incipient phases of product development is TRIZ (the Theory of Inventive Problem Solving) devised by Russian engineer Genrich S. Altshuller in 1946 and first published in 1956. This theory used for formulating problems, systems analysis, failure analysis and modelling of systems evolution is aimed at engineering applications and states that all technical systems follow predetermined laws of development and that solving models are repetitive [5].

The studies discussed in this paper are aimed at developing new gripper systems, light and eco-friendly, of *bionic* type. Gripping is achieved by means of original, selfadaptive, bio-inspired systems, with a *pneumatic muscle* as motion generator.

The proposed solutions of gripper systems are of non-anthropomorphic type with applications in industrial or medical robotics.

In addition to the novelty and originality of the proposed technical solutions, the paper opens up new avenues of exploration of compressed air utilization as an eco-friendly actuation agent and of pneumatic muscles as actuators made from new, light materials.

The method underlying the development of these new gripping systems is based on *design by analogy*, a strong working instrument aimed at widening the inspiration horizon in designing, at increasing the number of proposed constructive variants and, as a result, at setting up a data base of solutions for gripper systems deployable in various applications [6].

2. Design by analogy

Design by analogy represents a working method frequently used for the generation of new products and/or technologies. While in some cases this approach only draws upon knowledge from fields related to the nature of the product to be conceived, in others the ideas come from any field, related or not [7, 8].

Design inspired only from related fields is known as close-domain analogy, while drawing upon models found in any field is called cross-domain analogy.

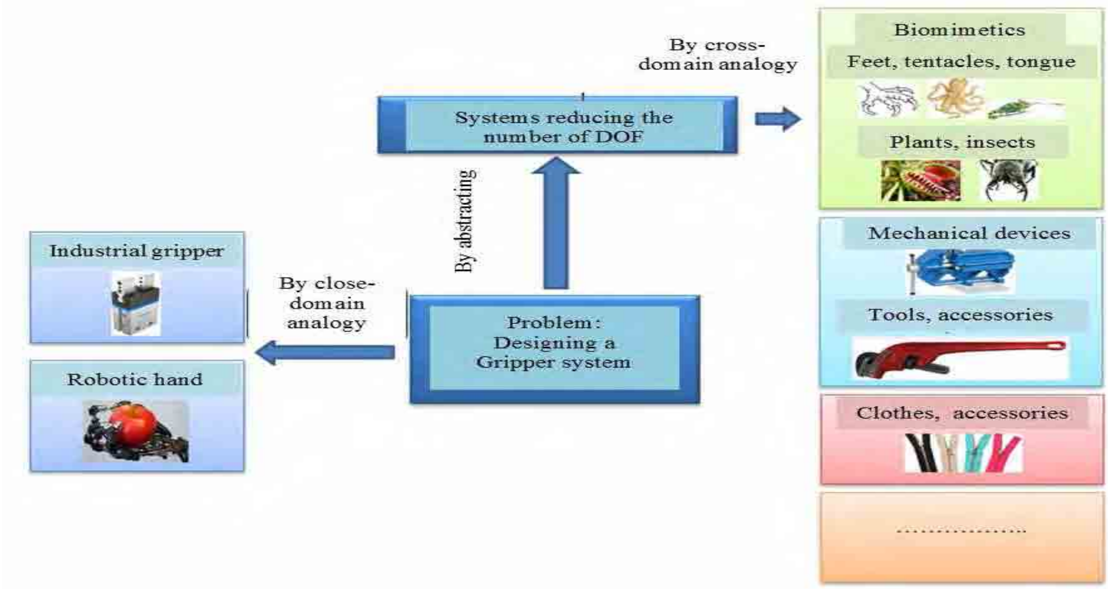

Figure 1. Types of design by analogy [6]

Figure 1 presents the two types of analogies, within the context of the discussed study aimed at designing a new gripper system. It can be noticed, that at abstract level the problem to be solved can be reduced to achieving a system that limits the degrees of freedom of a body based on models that come from nature, the technical environment, fashion, etc. [6].

As can be noticed in the figure, nature is a generous source of inspiration for developing new products. Numerous scientific papers address the systematic transfer of knowledge from natural sciences, from biology to engineering, emphasizing the huge potential of bionic (bio-mimetic) design for the development of new products and technologies [9].

2.1. Bionics

The functional morphology of living organisms regarded from an engineering perspective represents a permanent source of inspiration for innovative solutions of high-tech constructions. In this respect bionics (biomimetics), a novel scientific branch, combines knowledge of biology, mathematics, medicine and engineering. Bionics draws upon on biological intuition and engineering pragmatism to adapt nature's projects to the requirements of modern technics. Nature is but the starting point for innovations, it only offers clues as to what is useful in a mechanism. Starting from such clues it is the task of engineers to develop and refine the analysed system. Thus bionics represents systematic learning from nature, as opposed to "inspiration (copying) from nature" [10, 11].

The motive for bionics not having reached maturity to date is that from the engineering viewpoint nature is an unbounded complex beyond control. Nature does not "design" a structure in order to achieve an objective, as an engineer would do; it melds billions of random experiments conducted over thousands of generations, resulting in organisms whose goal it is to survive long enough to produce the next generation, thus launching the next round of random experiments [12, 13].

Regarded as a process, bionics can be approached *top-down* and *bottom-up*, respectively.

In the case of a *top-down* process (analogy bionics) the sequence of problems to be addressed includes:

1. Identifying and defining the problem;
2. Looking for analogies in nature;
3. Analysing examples from nature;
4. Searching for technical solutions for the defined problem, based on the identified natural models.

The *bottom-up* approach (abstractive bionics) involves the following sequence of problems to be solved:

1. Fundamental biological research: biomechanics and functional morphology of biological systems;
2. Identifying, understanding and describing the fundamental principle;
3. Abstracting of this principle (separation from the biological model and formulation in a universally intelligible language);
4. Searching for possible technical applications;
5. Developing technical applications in cooperation with engineers, technicians, designers, etc.

The role of the researchers is to apply either of the two visions in order to develop high-performance bionic systems adapted to achieving the set objectives.

2.2. Bionic gripper systems

An essential problem entailed by designing a new gripper system concerns the functional characteristics it is required to possess. Requirements such as developed force, rigidity / compliance, dexterity, number of degrees of mobility depend on the target application of the gripper.

At present grippers tend to become increasingly sophisticated, more complex, such as to satisfy increasingly varied requirements. A complex construction entails, however, high costs, often unacceptable within a competitive industrial scenario [6]. For this reason typical industrial applications currently use simple and reliable grippers, while more complex solutions, such as mechanical hands lends themselves rather for research purposes.

Figure 2 presents some of the differences between the characteristics of simple grippers and complex mechanical hands.

The most important characteristics of an industrial gripper system are the developed force and structural rigidity (the ones most influential of the positioning precision). The small number of degrees of mobility allow for the increased reliability of such a gripper and also for a smaller cost. Otherwise, complex mechanical hands have greater compliance and dexterity, similar to the behaviour of natural systems, thus recommending them for more delicate applications.

Natural gripper systems continue to represent an inexhaustible source of inspiration to engineers, who in time have developed a multitude of practical applications. Thus Figure 3 presents the concept of a person seizing a tomato with two fingers, and based on this the accordingly developed bio-inspired mechatronic system.

An artificial gripper system needs not only ensure the seizing of the object, but also its safe manipulation. In the above case of the tomato, for example, the developed force needs to be controlled, such as to not damage the seized object.

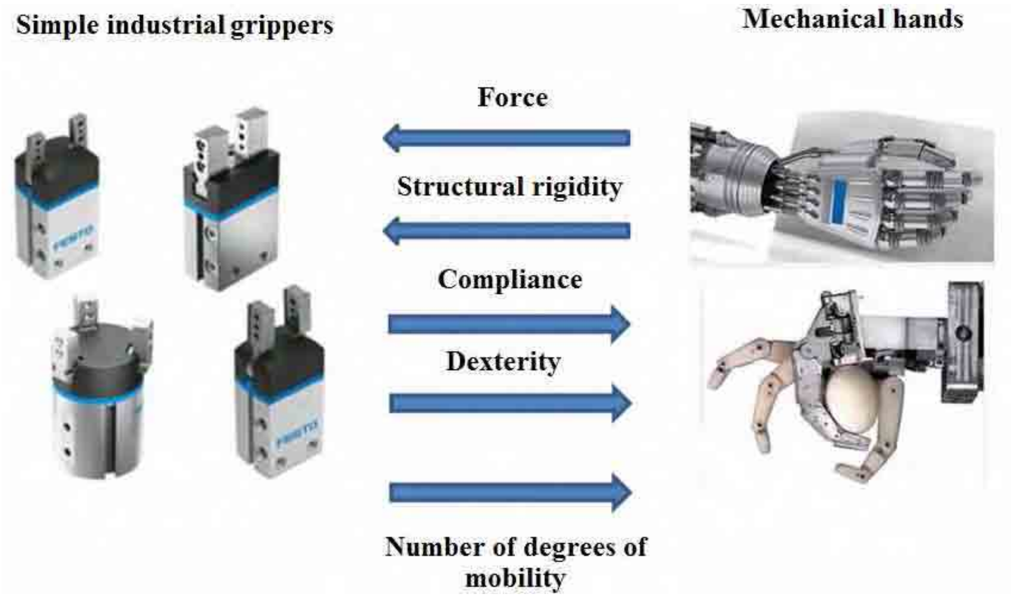

Figure 2. Comparison between the characteristics of industrial grippers and mechanical hands [14]

Figure 3. Transfer of the natural gripper model to an artificial system [15]

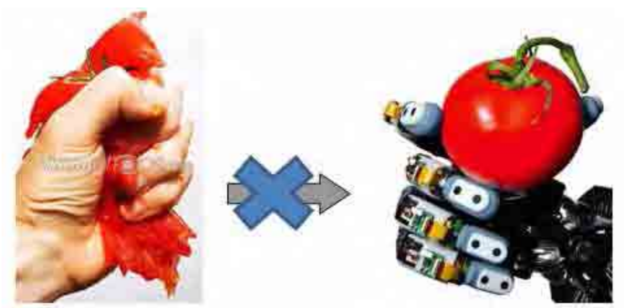

Figure 4. Gripping of an object by an uncontrolled/controlled force [16]

Starting from the above examples it follows that new, innovative bio-inspired gripper systems require light equipment of flexible structure with a high useful charge-to-eigenweight ratio, integrated position control and force control, all offered at a reasonable price. At present no gripper systems are available that would satisfy if not all, but at least most of these requirements.

For these reasons this paper discusses and proposes the solution of gripper systems actuated by pneumatic muscles – light and compliant bio-inspired elements, with a behaviour carrying a significant potential of yielding high performance robotic systems.

3. Pneumatic muscle actuated gripper system

This paper discusses a study with the main objective of conceiving an innovative bio-inspired gripper system, the novelty of that consists in its actuation by pneumatic muscles. For this a *top-down* bionic approach was used, drawing upon the principles of design-by-analogy. Such approach entails, upon formulating the problem, searching for systems in nature providing ideas for solutions. Several such ideas taken from the animal world are presented in Figure 5. The following step in analogy bionics is identifying technical solutions based on the selected natural models. As can be observed in Figure 5, in all cases gripping is achieved via mechanical contact forces. While in natural systems these forces are generated by muscles, in artificial grippers the forces are given by motors. Typically a mechanism consisting of rigid components is interlinked between motor and the gripper jaws (the effector elements).

The motor proposed for the new gripping device is a pneumatic muscle, which is a bio-inspired system analogous to animal and human muscles.

The pneumatic muscle copies, by biomimetics, the functioning of the human muscle fibre (Figure 6), with a number of features like shock absorbing capacity and shock resistance, low weight, small dimensions, reduced mass-to-power unity ratio and elasticity. These characteristics render pneumatic muscles into optimum constructive elements in robotics, for both orientation and gripper mechanisms.

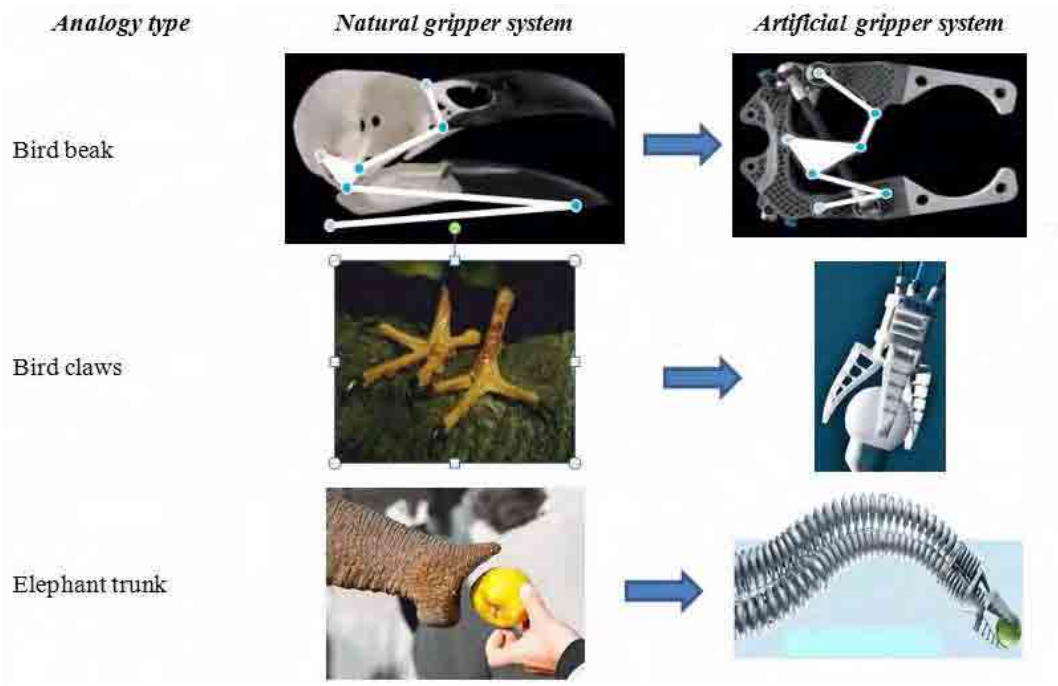

Figure 5. Natural gripper systems and their artificial copies [17]

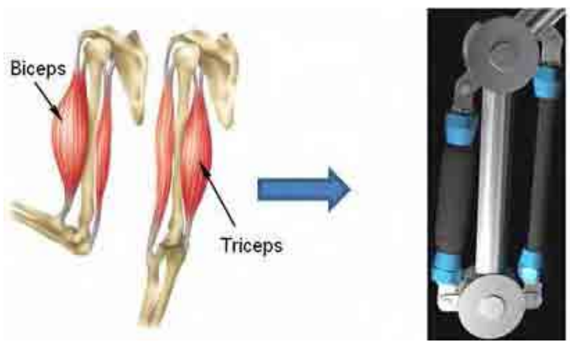

Figure 6. Antagonist operation of a pair of muscles [18]

Further a gripper variant is discussed with a pneumatic muscle as motor element and a gear mechanism for power transmission.

The proposed system consists of a single linkage with series-mounted components, with L = 2 exterior links. The system input is its link to the motor (pneumatic muscle), and its output is the link to the jaw-support.

Considering the functional and size-related requirements, the model discussed in this paper utilizes the smallest pneumatic muscle manufactured by FestoAG&Co, of 10 mm diameter and 45 mm length. The force generated by a 4 mm axial contraction of the pneumatic muscle is capable of sustaining and displacing an object of about 0.6 kg mass.

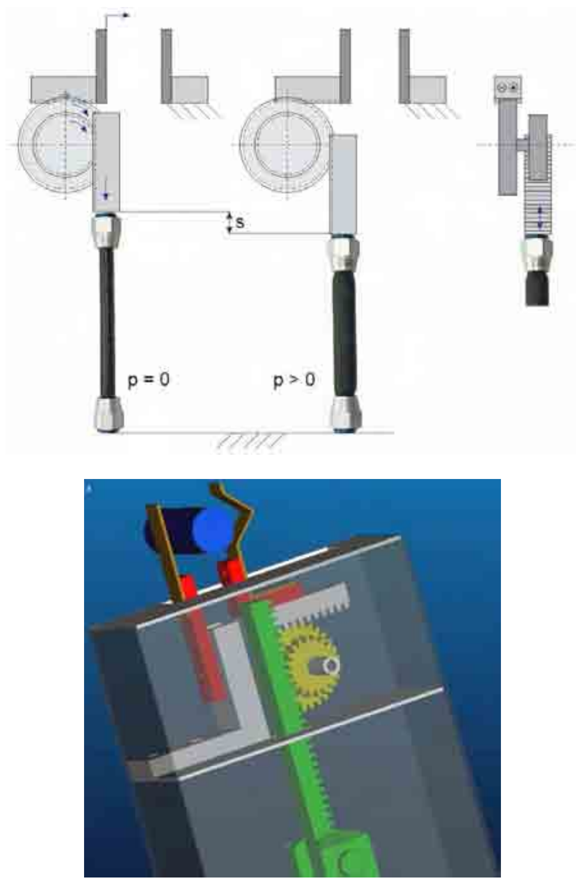

Figure 7. Asymmetrical parallel gripper system with a mobile and a fixed jaw

4. Conclusions

Design-by-analogy is a powerful working instrument for the development of innovative high-tech constructions. Starting from the functional specifications of the new products, seeking inspiration in nature yields surprising solutions adaptable to present technical requirements.

By means of the *top-down* bionic approach, that paper discusses a novel solution for a gripper system, based on actuation by a pneumatic muscle, whose construction and operation are inspired from nature.

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