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BIOMIMETIC ACTUATION OF NON-ANTHROPOMORPHIC GRIPPER SYSTEMS

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Rezumat. *Lucrarea prezintă etapele dezvoltării unor sisteme de prehensiune noi, bionice, eco-prietenoase şi uşoare. Prehensiunea se realizează prin intermediul unor sisteme originale, autoadaptive şi bio-inspirate, mişcarea fiind generată de un muşchi pneumatic. Metoda ce stă la baza dezvoltării acestor noi sisteme de prehensiune constă în crearea de concepte prin analogie şi se constituie într-un instrument destinat lărgirii orizontului de inspirație în proiectare prin utilizarea de modele din natură.*

Abstract. *The paper presents the stages of developing new, light, eco-friendly and bionic gripper systems. Gripping is achieved by means of original, self-adaptive, 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

The most important function of the human hand is that of gripping. The Romanian Language Dictionary (DEX) defines “prehension” as “the hand’s action of grasping, of seizing with the help of fingers, claws, tweezers, etc.”[1]. The gripping capacity of the extremities of the limbs can be found also in animals (for example lobster claws), reaching its highest degree of functionality in humans. Thus, combining of the independent motions of finger phalanges allows gripping, holding, moving and releasing various bodies.

The gripping function in humans entails a sequence of phases, starting with choosing the grasping method, followed by the actual seizing action and ending with controlling the manipulated object. Gripping is a consequence of desire generated internally or externally, that causes reactions at visual and brain level. Hence the hand is positioned close to the envisaged object, seizes it and carries out the programmed task. Figure 1 shows the phases entailed by gripping and the links between these [2, 3].

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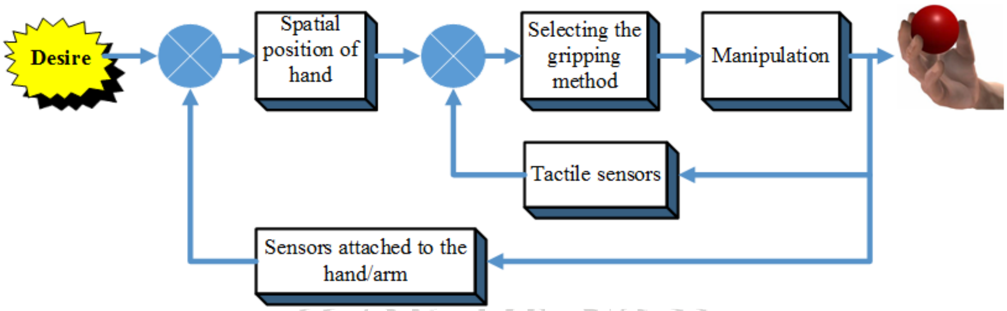

Fig. 1. Diagram of the phases entailed by gripping.

In the field of robotics gripping entails the contact between the effector element of a robot (the gripper) and a body in view of its manipulation. The grippers are those components of robot systems that facilitate the temporary contact with the manipulated object, ensuring its position and orientation during transport and assembly.

The studies discussed in this paper are meant to present novel, light and eco-friendly gripper systems of bionic type. Gripping is achieved by means of original, self adaptive, bio-inspired systems, with a pneumatic muscle as motion generator. The proposed solutions of gripper systems are of non-anthropomorphic type designed for industrial or medical robotics applications.

The method underlying the development of these new gripping systems is based on design by analogy, and is a powerful working instrument aimed at widening the inspiration horizon in designing, at increasing the number of proposed variants, and consequently at generating a data base of solutions for gripper systems usable in various applications.

2. Design by analogy

Design by analogy represents a frequently utilized method for the generation of new products and/or technologies. Numerous scientific papers address the issue of systematic knowledge transfer from natural sciences, from biology to engineering, and argue the enormous potential of bionic design (biomimetics) for developing new products and technologies [4].

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 since 1960 bionics (biomimetics), a novel scientific branch has developed, combining knowledge from biology, mathematics, medicine and engineering. Bionics draws upon 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 from (copying) nature” [5, 6].

Among the objectives of current bionic research, special attention comes to the study of effector organs. Their study, as well as that of the transmission processes of commands to them represents an essential part of bionics. In this respect terrestrial animals, birds and fish represent the source of inspiration for the development of various motion generating systems. Such an example is the study of the lizard’s climbing motion and the subsequent transfer of the obtained results to the project of a climbing robot (Fig. 2a) [7]. Another example is that of an aeroplane wing, a constructive solution inspired from the wing of a bat (Fig. 2b).

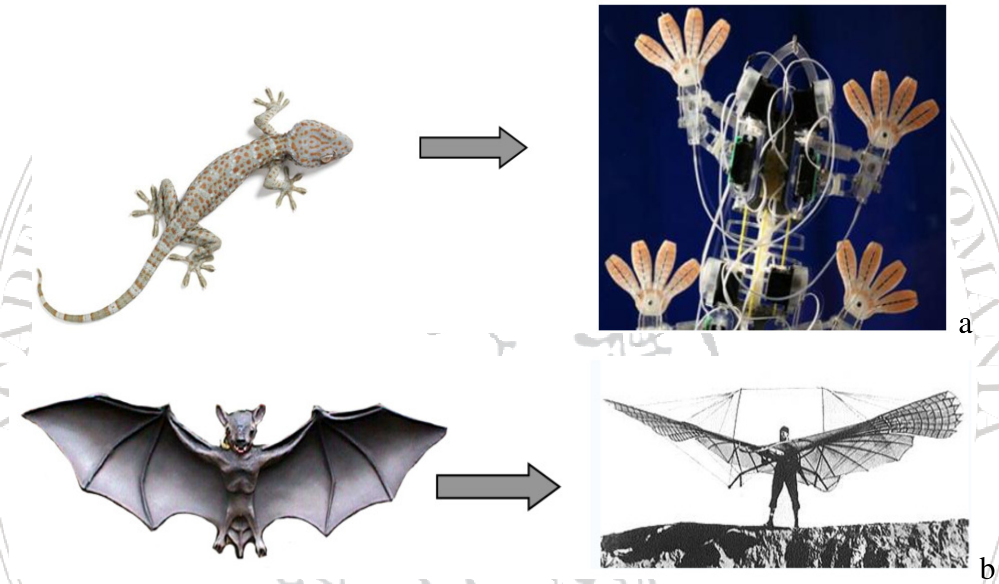

Fig. 2. Examples of biomimetics.

3. Gripper systems with bionic actuations

An essential problem related to the design of a novel gripper system concerns the functional characteristics this has to fulfil. Requirements like the generated force, rigidity/compliance, dexterity, the number of degrees of mobility depend on the application the gripper is designed for.

Natural gripper systems represent an inexhaustible source of inspiration for engineers, and in time they have underlain numerous practical applications. Thus figure 3 presents a mechatronic system bio-inspired from the seizing of a tomato by a person using two fingers and based on this the accordingly developed bio-inspired mechatronic system.

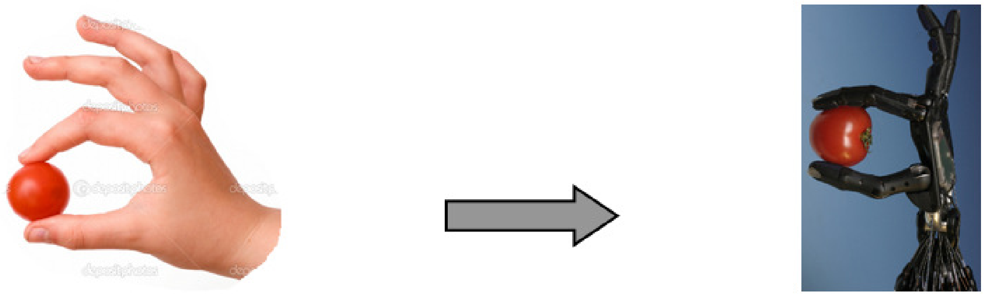

Fig. 3. Transfer of the natural gripper model to an artificial system

An artificial gripper system needs to ensure not only the seizing of the object, but also its safe manipulation.

Thus, in the case of the tomato of the above example, the magnitude of the applied force needs to be controlled, such as to not deteriorate the seized object. This is the case on compliant behaviour.

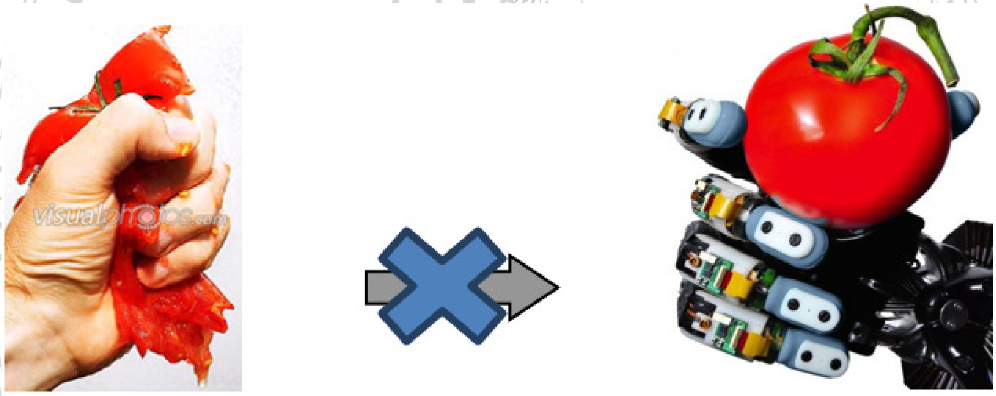

Fig. 4. Seizing the gripped object with an uncontrolled vs. controlled force.

Compliance, the inverse of rigidity represents one of the most important properties required from a gripper system. A compliant gripper system allows the safe manipulation of objects, without causing their deformation, by applying of forces of adaptable magnitude.

Such behaviour can be ensured by deploying adjustable compliant actuators – ACAs, like pneumatic muscles.

Figure 5 presents some of the main phases of the gripping process, namely approaching the object to be seized, initiation of the contact and its firm gripping between the two jaws by the application of an increasing force.

For these phases the classic profile of the jaws' velocities is presents, as well as the desired and necessary form of the curve that describes the compliance of the entire system.

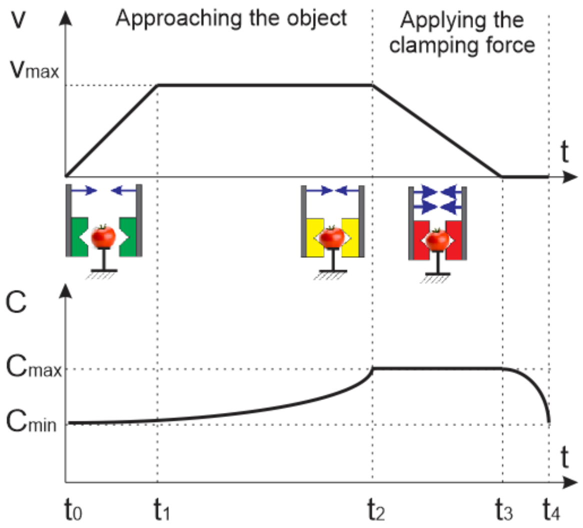

Fig. 5. Variation of the jaw velocity and of the compliance of a gripper versus time

The two graphs suggest that in the absence of contact between the jaws and the object, between moments t_0 and t_2 compliance can have smaller values, what allows a better positioning precision given by higher rigidity. The form of the curve that describes the variation of compliance needs to be concave, what allows a greater increase of compliance towards the moment of jaw-object contact initiation.

Between moments t_2 and t_3, when contact has been achieved, compliance needs to have the greatest values, thus ensuring the safe gripping of the object without its deformation/destruction.

An adjustable compliant actuator, like the pneumatic muscle, can adapt its functional behaviour between two limits. Thus its behaviour can vary from very rigid – required for a good positioning precision – to compliant, when the main requirement is the safety of the motion.

From the above follows that novel, innovative, bio-inspired solutions of gripper systems require light, flexibly structured equipment, with a high useful load-to-eigen-weight ratio, with integrated position adjustment and force control at an affordable price. Currently no gripper systems are available that would satisfy the majority of these requirements.

The paper aims at presenting innovative bio-inspired gripper systems the novelty of which consists in their actuation, namely with pneumatic muscles. In this respect the principles of design by analogy are applied via a top-down bionic approach. Such approach entails that subsequently to stating the problem, natural systems are to be identified able to provide ideas for adequate solutions.

Gripping is achieved by means of mechanical contact forces. While in natural systems these forces are generated by a muscle, in artificial grippers forces are generated by motors. In the novel gripper systems proposed in this paper the deployed motor is a pneumatic muscle, a bio-inspired system analogous to human and animal muscles. Between the motor and the jaws (the effectors) typically a mechanism intervenes, consisting of rigid elements. In this case the proposed gripper systems are based on gears.

The pneumatic muscle copies by biomimetics the functioning of the human muscle fibre (Fig. 6), and has a number of characteristics like shock absorbing capacity and shock resistance, low weight, small overall dimensions and mass per unit of power and elasticity. These characteristics render pneumatic muscles optimum constructive elements for applications in robotics, for both orientation and gripper mechanisms.

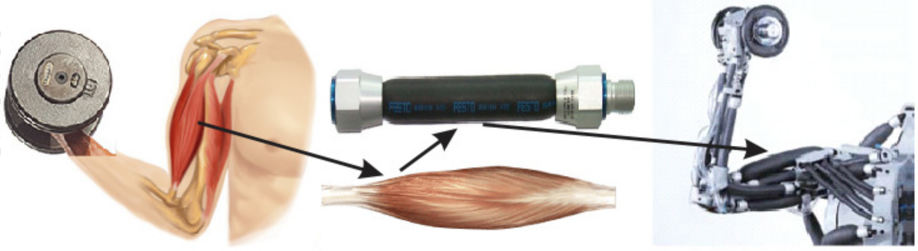

Fig. 6. Pneumatic artificial muscles mimic a biological muscle

Further on four variants of a gripper system are proposed, with a pneumatic muscle as the motor element linked to a gear mechanism for power transmission.

The pneumatic muscle actuated gripper systems were dimensioned based on the following input data: mass of the object $m = 0.7$ kg; acceleration of the motion of the system consisting of the gripper and the object: $a = 5$ m/s^2; gravitational acceleration: $g = 9.81$ m/s^2; emergency stop deceleration: $a_S = 10$ m/s^2; friction coefficient: $\mu = 0.2$; safety coefficient: $S = 2.5$. For these input data the maximum gripping force calculated for the various phases of the manipulation is of 86.67 N. [3]. As all variants of proposed gripper systems have two jaws, the force to be generated by the pneumatic muscle is double, of minimum 173.34 N (without considering the efficiencies of the linkages).

Considering the imposed requirements related to functioning and overall dimensions, the models proposed in this paper are based on the utilization of the smallest pneumatic muscle produced by Festo, Germany, (MAS-10-45N-AA-MC-O-ER-EG), with the following characteristics:

- muscle diameter: 10 mm;
- length of the active part: 45 mm;
- maximum working pressure: 6 bar.

Figures 7 to 10 show the schematics of the four variants of gripper systems.

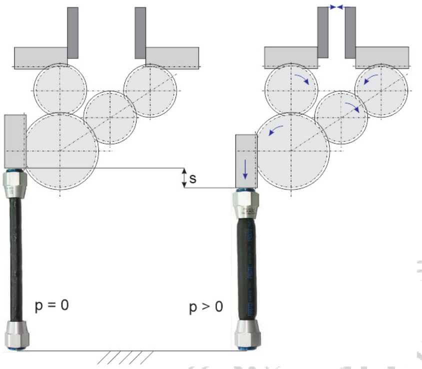

Fig. 7. Variant 1 (V1):
Parallel, asymmetrical gripper system
with two mobile jaws.

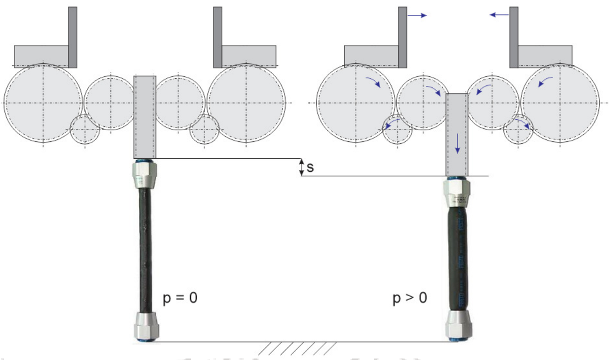

Fig. 8. Variant 2 (V2):
Parallel, symmetrical gripper system
with two mobile jaws

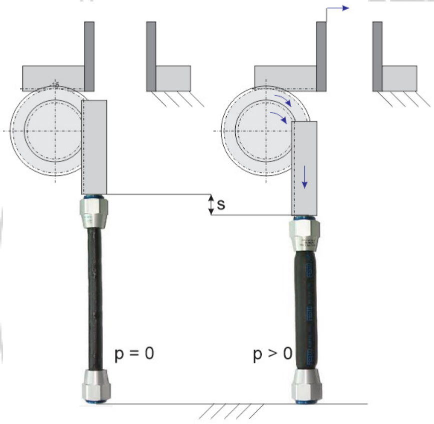

Fig. 9. Variant 3 (V3): Parallel,
asymmetrical gripper system with one
mobile and one fixed jaw

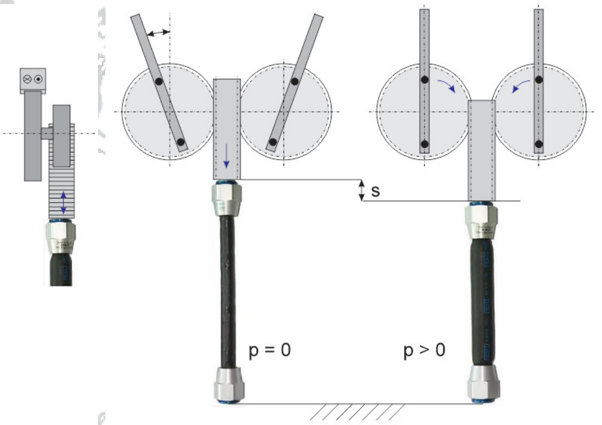

Fig. 10. Variant 4 (V4): Angular gripper system with
two mobile jaws

All the four proposed variants of gripper systems benefit from compliant behaviour, thus ensuring the safe manipulation of fragile objects, without deforming or destroying them. The utilization of a pneumatic muscle as an adjustable compliant actuator allows deviations from the position of equilibrium, their magnitude depending on the level of straining external forces.

Conclusions

The paper has presented several innovative constructive solutions of non-anthropomorphic gripper systems that ensure the safe seizing and manipulation of fragile objects. The idea of utilizing pneumatic muscles as actuators was taken from nature, by biomimetics, based on the functioning of the human muscle fibre.

The utilization of the linear pneumatic muscle as the actuator of the gripper system entails a light construction of significantly compliant behaviour, which corresponds to the safety requirements concerning the interaction with humans.

R E F E R E N C E S

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