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THE BIOLOGICAL ENGINEERING AS A SOURCE OF INSPIRATION FOR THE DESIGN OF THE ROBOTS MOVING IN THE PIPES

Summary. The paper describes the general method of utilization of research work concerning the selected groups of living organisms. The results of this work can be serve as a base for the construction of new mobile robot. The general algorithm of operations connected with the analysis of the motions of living organisms as well as the method of synthesis of their kinematics have been presented.

Example of new constructions of robots gripper built on the basis of the analysis of invertebrates grippers are presented.

Introduction

The search for new solutions concerning, among others, construction problems in machine design, led to a development of bionics, a science branch combining biology and technique. Bionics deals with a systematic application of the research on living organisms in order to solve various technological and construction problems. Using biological analysis to model mechanical constructions leads to proposals of new solutions. Bionics is closely linked with biological engineering. It deals with a living organism treated as a biological system, which functions in a specific environment. A methodical study of the functions of a living organism, and an application of the results in machine-building leads to additional solution variants of a technical problem. It is particularly useful in the robots design, where functional assumptions are often difficult to realize and differ from the existing solutions. For instance, in the case of the mobile robots design, it is possible to make use of the ways in which some animal groups move. It is, therefore, possible to analyze a number of hitherto unknown kinematic systems. Kinematic systems, obtained in this way, may serve as a basis for design of new robot types. Such analysis may also involve the equipment of robots, allowing for an expansion of the scope of their operations.

Design method

To design a construction using the information about a specific group of living organisms, acquired during the biological research, biologists and engineers have to co-operate. Even, in a relatively narrow branch involving ways and systems of movement, a slightly modified scientific approach is required; in particular, it is necessary to understand the differences between biological and technical studies. A descriptive character of the studies, typical for biology, ought to be widened and include an explanation of the way in which the observed functions of a living organism are realized. The biologists co-operating with engineers should be also aware of the conditions, possibilities and requirements characterizing the engineering industry. Likewise, the engineers should take into consideration the basic differences characterizing an organism, if it is viewed as a system. In contrast to a technical system, an organism is an open system; it possesses a remarkable efficiency; there are dynamic processes occurring in it; it stays alive, owing to a continuous exchange of parts. The following comparison of the biological and technical systems moving in the water and in the air may serve as an example of the differences occurring between technical and biological systems (Fig.1 a, b).

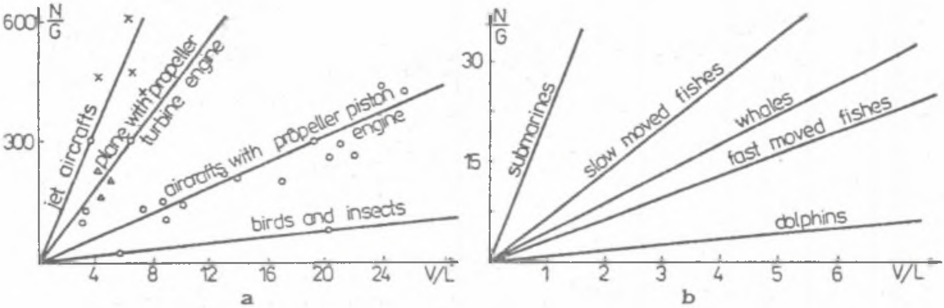


Fig.1. A comparison of movement capabilities of living and technical objects

In Fig.1, we present the dependence of the so-called unitary velocity (the velocity with which an object moves in relation to its greatest length in the direction of the movement: $\frac{V}{L}$ / $\frac{1}{sec}$) in the function of the function of the so-called unitary power of an object (the driving power of an object in relation to its mass: $\frac{N}{G}$ / $\frac{kW\,sec}{t}$). That comparison, both for the air- and water-borne objects, is unfavorable for technical objects.

The above presented example confirms that it is sensible to look for solutions to technical problems in nature. Engineers must become acquainted with the richness of forms and taxons of the organic world, and to understand the regularities occurring in it. They must take into consideration not only the specific character of the studied organisms, but also the scatter of the results of those studies, due to individual characteristics, the influence of evolutionary processes, and the degree of adaptation to specific ecological conditions. The complexity of the above presented characteristics of living organisms makes a mathematical description of the functioning of a living organism (which would be typical for a technical object) an equally complex, if not an impossible, task. This can hardly be accepted by engineers, who operate on exact data; particularly, in the domain of construction.

An attempt at a methodological formulation of actions, with the application of biological research in machine-building, is presented in Fig.2. In this case, the kinematic system of a robot is involved. We can distinguish three construction stages:

- definition and description of the basic function of a technical object, including the conditions under which the object is to perform, and the occurring limitations. Distinction of partial functions, and selection of the function which is subject to biological research;
- analysis of analogous functions in the chosen groups of living organisms: determination of the degree to which the functions are analogous, and a detailed description of the realized function in the chosen groups of organisms;
- synthesis of the described way of the function realization by the organisms. Building of simplified models of technical systems, which can serve as proposals of construction solutions during further designing stages.

The above presented algorithm is very general, and represents only a basic method of approaching the problem. It does not always happen that a very complex function (for example, the movement of an object in specific conditions) is investigated. Sometimes, the assumptions may be more simple and, then, the search for new solutions among living organisms does not require such a laborious investigation.

We can distinguish, at least, three fields where solutions, coming from biological research, are applied in technique:

- adaptation of a specific characteristic of an organism in order to make it applicable in technique. There are numerous examples; we shall mention the following: a claw-shaped lock, the ways of animal camouflage, or the suppressing stratum of a dolphin's skin;
- modelling the activity of a simple organ, or of its part, realizing a relatively simple function, such as catching, carrying, or holding the prey;
- modelling the activity of an organism realizing a very complex function, including the environmental conditions, and (possibly) the way of energy conversion. It may involve, for example, moving in a specific way: leaping, walking in a limited space or conditions.

In the case of robotics, the second and third field of biological research application, are particularly interesting. The greatest interest is arisen by the investigation of simple functions. Preliminary investigations show that it is more expedient to conduct research on simple-structured organisms, the invertebrates. Among *Coelenterate*, *Annelida*, insects, and *Mollusca*, we could find solutions, serving as the basis for new constructions. An extraordinary richness of forms, and a more simple analysis, allows us think that, for engineers, it will be an interesting, and a little-known source of inspiration.

In contrast to other groups of organisms, invertebrates have not been widely investigated with the view of obtaining proposals for new solutions in robotics. Higher organisms, vertebrates, were more often subject to investigation: the movements of quadrupeds, or, the mechanism of the elephant's trunk. Effects, resulting from biological investigations, may be exemplified by the inspection robot, moving in pipes. In order to find a construction solution,

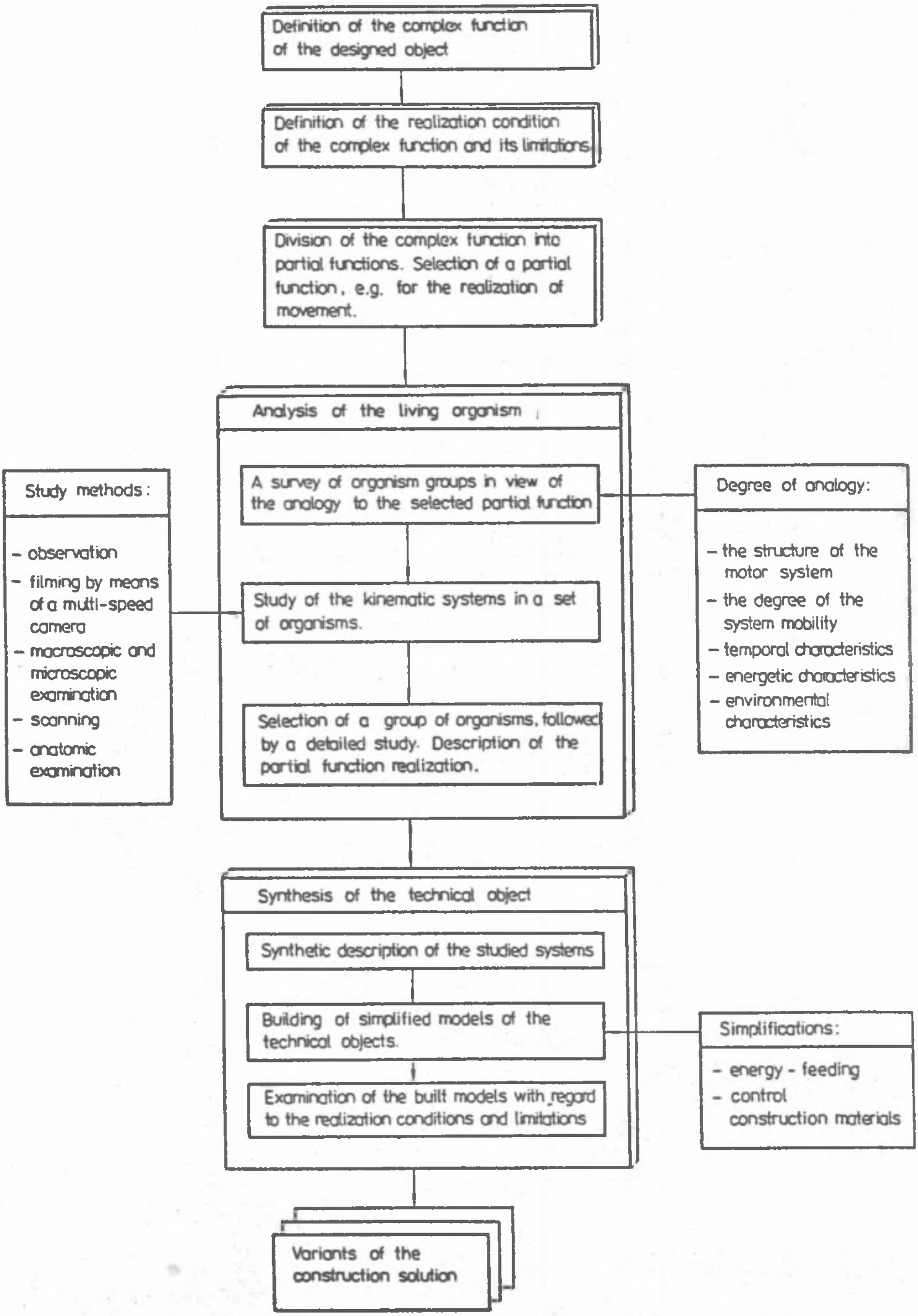


Fig.2. An attempt at a methodical approach towards design based on biological research

a survey of selected groups of invertebrates was made, including *Coelenterate*, *Ulothrix*, *Annelida* .

Particular attention was devoted to the class of Oligochaeta from the phylum of Annelida. They live in the soil, and make tunnels therein. Their biological function of moving is, therefore, similar to the functions of the designed machine, and the conditions they live in resemble the conditions in which the robot is to function. Earth-worms (Lumbricidae) are typical representatives of this class, and they became the objects of a detailed morphological analysis. An observation of their way of moving was carried out.

A characteristic feature of the earth-worm, just like of any other Oligochaeta, is body segmentation (Fig. 3a). While their volume remains constant, the diameter and length of the segments change under the influence the longitudinal and orbicular muscles.

a) Segmentation of the earth-worm

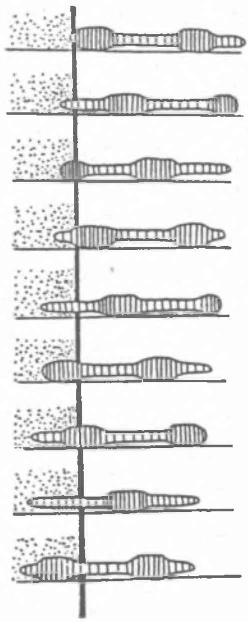


Fig.3

b) Muscels of the earth-worm c) Earth-worm boring a tunnel

In the earth-worm's body, under the cuticle and epithelium, there is a relatively thin layer of orbicular muscles. Underneath, four strands of longitudinal muscles are located, close to the circumference. On the outside, there are numerous mucus producing glands, and, what is important for the way of moving, there are tufts of stetae. Segment partitions are heavily muscled, which helps to keep them tense while the segment diameter is changing, and protects inner organs from being squashed (Fig. 3b). The muscles are unevenly distributed within the body: in the front part, they are more than 50% of the total volume, and in the back, only 25%. Contraction waves caused by muscle activity occur in adjoining segments and are repeated 5-12 times per minute.

When it begins to move, the earth-worm contracts the longitudinal muscles of its front segments. They increase in diameter, and decrease in length. Simultaneously, the setae straighten and catch on the irregularities of the earth's surface. Then, the front segments become elongated due to the orbicular muscles contraction and longitudinal muscles loosening, and the front part of the body moves forward. The contraction wave moves backwards, and in the front part another longitudinal muscle contraction occurs (Fig. 3c).

This enables the animal to move forward and make tunnels in the soil. The displacement of the earth-worm is discontinuous. There are intervals during the maximum contractions of the longitudinal muscles. Each body elongation is about 2-5 cm. The speed, dependent on temperature and moisture, can be as high as 2,5 cm/sec.

The analysis of the earth-worm motor system allowed us to make several models reflecting the worm's movement. Finally, we decided on the model presented in figure 4. The model consists of several independent units linked with joints. They exert alternately radial, expansive, and axial forces moving the device discontinuously in the pipe. A patent for the presented solution was obtained.

Robot's Construction.

Work Area

The work area is limited on the outside by cylindrical surfaces and sections of circular rings connecting the surfaces. The robot can move in the pipeline with the straight axis, and in the ring-shaped elbows. It is of no consequence how the work area defined in such a way is located in the gravitational field (Fig. 5). The length of the pipeline is dependent on power supply to the robot, and, in the case of cable power supply, it is restricted. The pipeline diameter, depending on the construction variant, may range between 150 and 200 mm, or between 250 and 500 mm. It is also assumed that the pipeline diameter changes only very little lengthwise, and the pipeline is not filled with any medium.

Robot's Modules.

Based on the bodily segmentation of the earth-worm, the module construction of the robot guarantees that the modules exerting radial and axial forces work repetitively. It also leads to a simplification and technological improvement of the construction (Fig. 6).

The robot consists of two modules connected with joints, which exert radial forces upon each other, and move axially in relation to each other. The modules are supported on a wheeled undercarriage placed every 120° in the plane perpendicular to the axis. The undercarriage is equipped with an elastic suspension for better adherence of the wheels to the walls. The units exerting radial forces are also spaced every 120° in the modules. The unit exerting axial forces is placed in the back module. It is a double-sided pneumatic drive. The drive is attached on a parallel base, and in this way, in the robot's axis of symmetry, we got a port allowing us to conduct cables supplying power to the robot's replaceable gear installed in the front module.

The robot's motion consists of two cycles. In the first cycle, the front module exerts radial forces on the inner walls of the pipeline, and the back module moves axially. In the second cycle, the back module exerts radial forces on the walls, and the

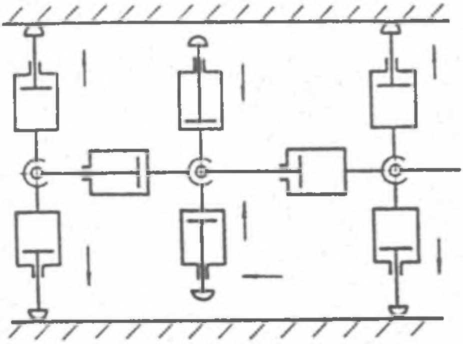


Fig.4. Model of the earth-worm movement

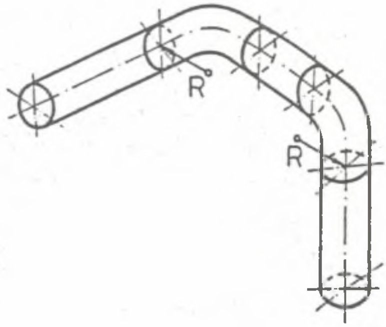
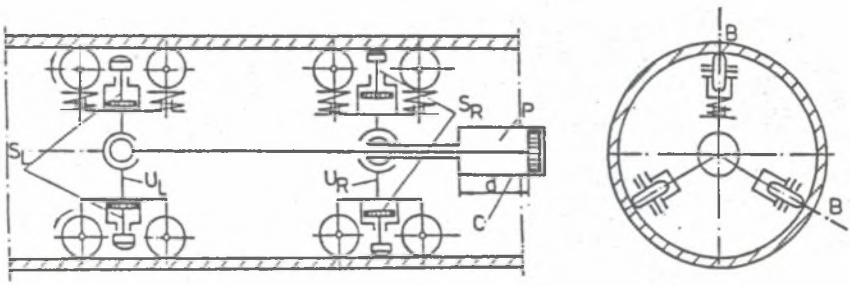
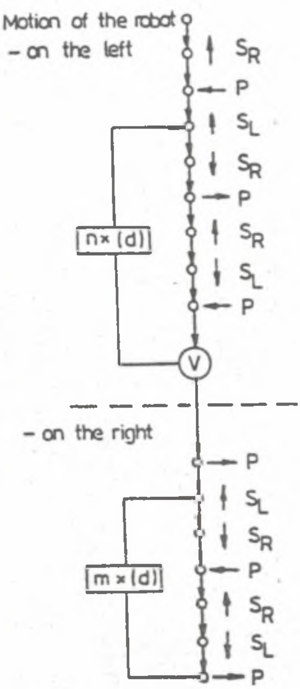


Fig.5. Shape of the work area





U_R, U_L - front, back segment of the robot
S_R, S_L - front, back struts
P, C - piston, cylinder
↑S_R, ↑S_L - operating conditions, or space motion of the struts
↓S_R, ↓S_L - standstil or backward motion of the struts
←P (→P) - state, position or the motion of the piston on the left (on the right) relative to the cylinder

Fig.6. Kinematic scheme of the robot

front module moves axially. In this way, the robot covers a definite length of the path.

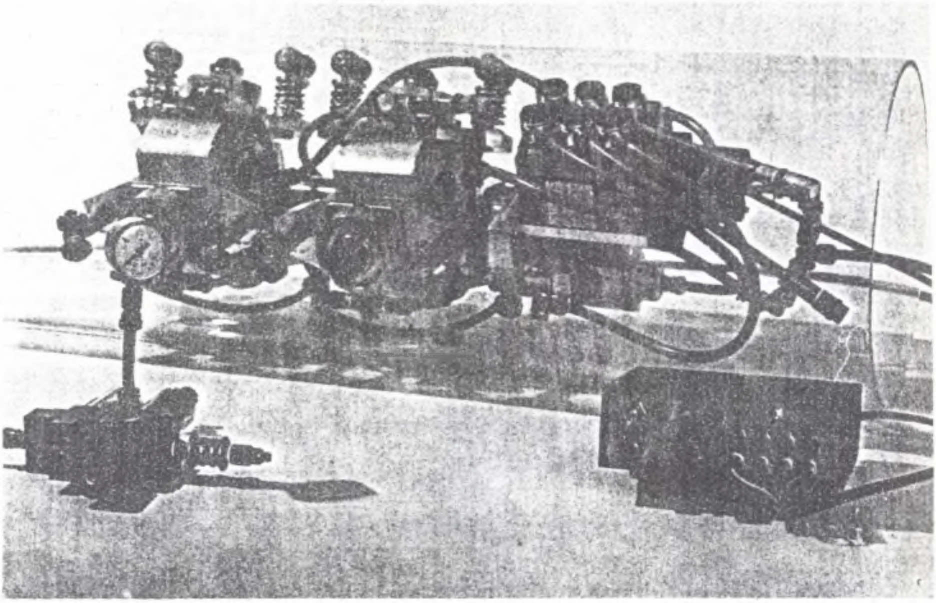


Fig.7 A prototype of the inspection robot on a special research station equipped with a transparent plastic pipe

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BIOLOGISCHE FORSCHUNGSARBEITEN ALS EINE INSPIRATION FÜR DIE PROJEKTIERUNG DEN, IN DIE RÖHREN, SICH BEWEGENDEN ROBOTER

Zusammenfassung

In Referat ist eine allgemeine Methode der Ausnutzung der biologischen Forschungen in der Technik und besonders in der Konstruktion der Roboter vorgestellt. AlsBeispiel ist ein Robot auf Grund der Untersuchungen des Regenwurmes konstruirt, welcher sich in Röhrleitungen bewegen kann, gezeigt.

INŻYNIERIA BIOLOGICZNA JAKO ŹRÓDŁO INSPIRACJI KONSTRUKTORÓW ROBOTÓW PORUSZAJĄCYCH SIĘ W RURACH

Streszczenie

W referacie przedstawiono ogólną metodę wykorzystania badań biologicznych w celu wykorzystania wyniku w technice, a w szczególności dla konstrukcji nowych rozwiązań robotów mobilnych. Przedstawiony został przykład robota inspekcyjnego poruszającego się w rurociągach, który został skonstruowany w oparciu o badania nad dżdżownicą.

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