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ANALYSIS AND MODELING DESIGN OF PROTOTYPES OF THE LIMBS OF ZOOMORPHIC ROBOT

It this article basics of bionics were considered, such as biological principles of mammals, from cat family, musculoskeletal system building is examined, namely – arch of pelvis and its muscular system. Based on its detailed analysis 3D model of cat limb was modeled and offered, then, after modeling static burden in CAE ANSYS, with subsequent analysis of its robustness and suitability for future use in real robotic systems.
Key words: modeling, designing, analysis, bionics, musculoskeletal system, zoomorphic robot .

Євсєєв В.В.Волобуєв В.С., Салієва В.Э. Розробка і моделювання конструкції кінцівок зооморфного робота. У цій статті розглянуті основи біоніки, такі як біологічні принципи побудування опорно-рухового апарату у ссавців сімейства котячих, а саме: тазовий пояс кінцівок кота та його м’язовий скелет. На основі його детального аналізу була змодельована і запропонована 3D модель конструкції задньої ноги кота та проведене моделювання статичного навантаження в CAE ANSYS, з подальшим аналізом міцності та придатності використання цієї конструкції у майбутньому, для будування реальних роботизованих систем.
Ключові слова: моделювання, конструювання, аналіз, біоніка, опорно-руховий апарат, зооморфний робот.

Евсеев В.В., Волобуев В.С. Салиева В.Э. Разработка и моделирование конструкции конечностей зооморфного робота. В статье рассмотрены основы бионики, такие как биологические принципы построения опорно-двигательного аппарата у млекопитающих животных семейства кошачьих, а именно: тазовый пояс конечностей кота и его мышечный скелет. На основе подробного анализа была разработана и построена 3D модель конструкции задней лапы зооморфного робота, и проведено моделирование статической нагрузки в CAE ANSYS, с последующим анализом прочности и пригодности использования этой конструкции в будущем, для построения реальной роботизированной системы.
Ключевые слова: моделирование, конструирование, анализ, бионика, опорно-двигательный аппарат, зооморфный робот.

Formulation of the problem. One of the trends of robotics evolution is development of zoomorphic robots, designed on the basis of physiological traits of living creatures building. Leading developers in this area – Boston Dynamics and their prototypes – Spot[1] and SpotMini[2], Festo Corporate, which developed zoomorphic robots like BionicANTs[3], BionicKangaroo[4], BionicCobot[5] – are showing relevance of this researches and their necessity for the progress of robotics in future. Researches in the field of bionics are giving opportunity to create zoomorphic robots with dynamical characteristics of movement which are close enough to real prototypes of living creatures. Complexity of development of such robotics systems is based on projecting limbs with systems of smooth movements and damping, which could give us necessary smoothness of moving and don’t reduce robot’s movement value, and don’t decrease its passability.

Goal of this work. Main goal of this article is considered in 3D Solid Works model of hind limb of zoomorphic robot developing, with an mammal from cat family as prototype. Then, carrying out modeling of loads was taken for adequate rating for proposal of offered design. On basis of these researches zoomorphic robot will be developed, ruled by Raspberry PI 3 [6] or LattePanda[7], which could give an opportunity to create an imitation of behavior, using artificial intelligence.

Part of the earth's surface is difficult to overcome or cannot be overcome for traditional wheeled and caterpillar vehicles, because there are various kinds of obstacles on the surface (natural - various relief formations, stones, trees, etc.). At the same time, animals and people can move around rough terrain without difficulty. That is why for robots that are used to move over rough terrain, developers use the so-called "stepping" platform. The high passability of robots, moving on their feet, caused the relevance of their development [8], as they can be used in search and rescue operations, for exploring rough terrain, and reconnaissance. The use of legs as a locomotive system of the robot makes it possible to increase the passability and make it possible in areas with an inhomogeneous, highly rugged terrain, since the walking robot uses a small area for support during movement and thus does not create significant pressure on the surface.

When designing zoomorphic robots, the most promising solution is the adoption of motion algorithms in representatives of living nature (insects, mammals, arthropods) [9]. For this, it is required to carry out bionic studies related to a specific bionic sample in order to track all its habits and features in order to correctly reproduce the necessary functions in the robot. Bionics is an applied science about the application of the principles of organization, properties, functions and structures of living nature in technical devices and systems, i.e. living forms in nature and their industrial counterparts. The main areas of bionics include: analysis of the nervous system of a living organism, the study of sensory systems, the embodiment of the principles of the operation of biological systems, the use of knowledge about the structure, functioning, chemical and physical interaction of living organisms.

The constructive systems of living organisms are formed according to the principle of saving materials and ensuring the reliability of the structure; therefore, two main principles are highlighted out in bionics: the methods of natural constructions should be used reasonably in engineering, and tendency to minimize costs in the technical products being sold [10].

Despite the fact that the structure of living organisms is much more complicated and versatile than those that were ever created by man, since living organisms are characterized by the ability to perceive even the smallest changes in the environment, to remember and take into account these changes in their further behavior, and respond to them, based on previous experience.

Technical systems created by man do not have an internal dynamic balance, and in this sense they are static. In living nature, we are dealing with organic structures and tissues that are continuously destroyed and restored, and the permanence of their forms is maintained through continuous restoration, and this difference from the technical and technological point of view is very significant; similar artificial models with similar principles have not been created yet. Also, unfortunately, modern science is not able to repeat another important element that is present in animals – muscular system, which significantly complicates the development of the limbs of their bionic prototypes, since there is need to simulate their presence and action in a variety of ways for the correct limb functioning.

Consider an example of a bionic study - the development of a prototype of a hind leg for a zoomorphic robot, the prototype of which is an animal from the cat family.

Fig. 1a shows the pelvic girdle of the cat's limbs.

a) b)

a) pelvic girdle of a cat: 1 - iliac bone, 2 - ischium bone, 3 - hip joint, 4 - femur, 5 - patella, 6 – tibia, 7 - knee joint, 8 - hock, 9 - tibia, 10 - hock joint, 11 - metatarsus, 12 – fingers;

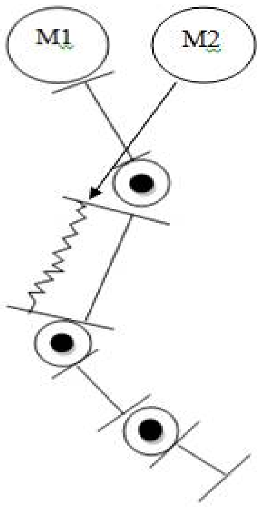
б) muscular skeleton of the cat: 1 - sartorius muscle, 2 - gluteal muscles, 3 - biceps femoris, 4 - gastrocnemius muscle;

Figure 1

The bones of the hind limbs are better developed than the forelegs and are more rigidly attached to the spine, since they bear the main load when jumping, for example, metatarsal bones are twice as massive and longer as the wrists on the forepaws. The muscular system of the hind paw is shown in Fig. 1b. The muscular system of the pelvic girdle is one of the most developed in the cat, which makes it possible for him to jump far and high.

Analyzing the structure of the cat's hind paw, the conclusion was drawn that its design needs to be divided into two parts: the design of the bone skeleton of the limb and the design of the means that replace the muscular skeleton of the limb.

On the basis of the carried out bionic analysis, a kinematic scheme for the transfer of motion from servo motors to limbs is given in Fig. 2a. Fig. 2b presents the results of researches in the form of a 3D model of the detailed assembly of a foot of a zoomorphic robot, completed in CAD SolidWorks.



a)

b)

a) kinematic scheme;

б) hind limb of a zoomorphic robot;

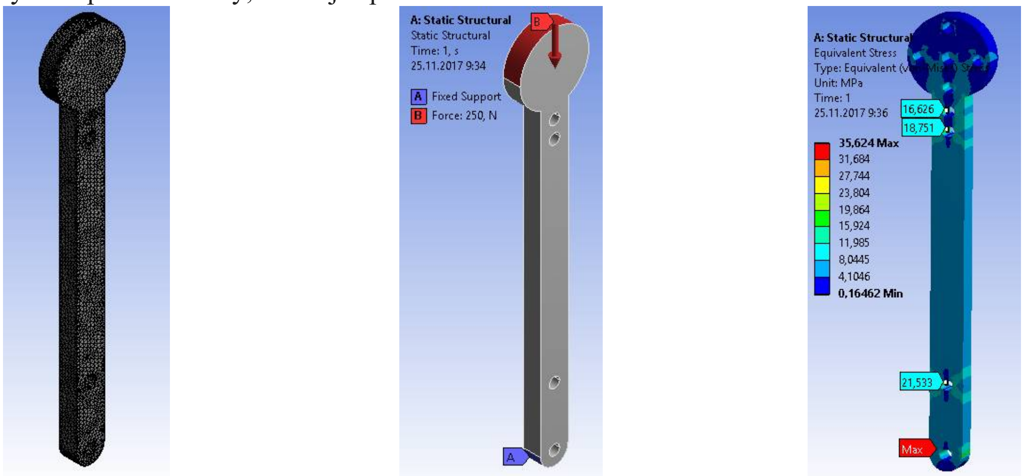
Figure 2

To evaluate the designed model, it is necessary to check the correctness of chosen dimensions (whether design with such parameters will withstand the weight of the robot). For this, the main assembly details undergo an evaluation of the bearing capacity. The part is viewed as a cantilever beam fixed at one end and under the action of the loading force F from the other end [12]. Since finite mass of the robot is not known to us, limiting value of the loading force F will be used for evaluation, at which equivalent stresses exceeding the yield strength (since the load is static) of the material will be observed. Details are planned to be made on a 3D printer, so the material will be ABS plastic. The main characteristics of the material are given in Table. 1:

Table 1 – Main characteristics of ABS plastic

Property	Value	Unit
Density	1040	$kg{\cdot}m^3$
Young`s Modulud	2.6E+09	Pa
Poisson Ratio	0.35	
Bulk Modulus	2.8889E+9	Pa
Shear Modulus	9.6296E+08	Pa

To analyze the part from the assembly, shown in Fig. 2b were imported into CAE ANSYS. Since the analysis in this program is based on FEM, surface of the model is divided by a grid of finite elements - Fig. 3a. The grid size is selected based on the dimensions of the part, to ensure sufficient calculation accuracy. Next, the settings of analysis are set up of Fig. 3b, and the last step is to analyze the results. In Fig. 3 it is seen that at a load of 250 N (corresponding to a mass of ≈ 25 kg, equivalent stresses exceeding the yield strength of the material, which is 34-52 MPa, appear in the workpiece [13]. Consequently, with this load, the parts quickly collapse. Similarly, all major parts were modeled.



а) б) в)

Figure 3 – Analysis of part of the robot's legs

Conclusions. In this article, the fundamentals of bionics and principles of constructing the limbs of zoomorphic robots were considered; the principle of bionic analysis was shown using the example of the design of the robot's rear leg. Based on the analysis of the musculoskeletal system of the hind limb, a kinematic scheme was drawn up and a detailed assembly of the leg in CAD SolidWorks was developed. Evaluation of the designed parts in CAE ANSYS has shown that the maximum load on the workpiece must not exceed 250 N, therefore the mass of the whole structure should not exceed 25 kg. In the future, the results of the study will be implemented in the form of a robot layout.

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