Hardware-software complex of in-depth studies of hexapod walking robot

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Abstract. A hardware-software complex of in-depth studies of hexapod walking robot including the hexapod mockup and its simulator is described. Possible applications of the complex for the study of statically stable hexapod gaits and obstacle clearance algorithms are considered. An important feature of the simulator is the ability to work in real time that allows you to use it in the control loop.

1. Introduction
To work in areas that are inaccessible or dangerous for humans, it is necessary to develop new types of robots that can autonomously or by the operator's command avoid obstacles, overcome blockages, climb stairs, and so on. One of the possible ways to solve this problem is the use of a six-legged walking robot – hexapod, Figure 1.

Figure 1. Hexapod.
Figure 1 shows the “Snowflake” hexapod made for research purposes. The robot parts are designed in the SolidWorks system and printed on a 3D printer made of ABS plastic. As it is known, for the static stability of the robot it is enough constant reliance on three legs. Therefore, for six-legged machines it is possible to synthesize a statically stable gait in any of its phases and the ability to maintain this stability even with a partial failure of one or even two legs. An important feature of hexapods is the flexibility in the formation of the initial (starting) orientation and the possibility of maintaining this orientation in the process of movement, even when obstacles are overcome, regardless of the direction of motion. This can be useful when monitoring (video inspection) of the environment or when transporting goods sensitive to impacts or turns in space.

An analysis of available publications, for example [1-3], shows that currently there are no techniques for designing the considered class of mobile robots that are acceptable for practical application, there are no techniques for designing control systems for their movement. In this connection, there is a need to develop means for studying hexapods with the subsequent development of the main provisions of the engineering method of controlling their movement.

2. Hardware-software complex
The hardware and software complex includes a hexapod mockup and its simulator. The structural diagram of the complex is shown in Figure 2.

The simulator is intended for verification of kinematic models and development of control algorithms. Gives a good repeatability of experiments independent of the servo drives, the condition of the communication channel, temperature and other external factors. In the simulator it is easier to debug the control algorithms, because we have full information about the simulated objects and we can control the simulation progress, incl. stop it. Experiments, successfully conducted in the simulator are then repeated using the physical mockup of the hexapod.

As you can see in Figure 2, the simulator is based on web technologies. The client does not need to install any software, it is enough to have a modern web browser with support for WebGL, WebSockets and Web Workers. The server is written in Node.js, MongoDB is used as the database. Deployment of the server is possible on most popular operating systems today, including Windows, Linux, Mac OS.
Experiments can be easily parallelized. Calculations are made on the client side, i.e. The more customers - the more processing power.

As can be seen from Figure 1, the hexapod "Snowflake" has a radial symmetry and is made according to an insectomorphic scheme. Each of his six legs has three degrees of freedom - one in the horizontal plane and two in the vertical plane.

Currently, the hexapod is controlled through a simulator. The researcher is given two types of interfaces: high-level and low-level. The low-level interface gives access to the rotation angle of each of the 18 servos and can be used to synthesize various gaits by the researcher. A high-level interface is provided to the operator for solving applied problems and investigating intelligent control algorithms: path selection, obstacle clearance, etc.

In the hexapod there are 18 servo drives, the control of the operator behind each of them in real time seems inconvenient and impossible. The joystick is a familiar and convenient controller, therefore, based on the high-level API, methods for managing the hexapod using a joystick and a conventional keyboard have been developed and tested, figure 3. In addition, the user is provided with a low-level API for developing his own methods and techniques of control.

![Joystick control](image)

**Figure 3.** Joystick control.

On the basis of the software and hardware complex, a number of experiments were carried out. In particular, the gait of the physical sample of the hexapod on a smooth surface is adjusted. And in the simulator, experiments were conducted to overcome various obstacles.

At this stage hexapod does not have a system of technical vision because of its great technical complexity. The lack of a visual system is easily replenished by a simulator, with which you can simulate the state of the surrounding space, the surface of the robot's movement. So when simulating the overcoming of an obstacle, for example, moving a robot along the steps, the operator is able to fully control the position of its hull, which can be useful when working out algorithms for transporting goods that are sensitive to position in space or impacts. And this kind of movement is an important feature of walking robots, which is inaccessible to wheeled and caterpillar vehicles.

**3. Main results**

In the course of research using the software and hardware complex, the following results were obtained:
- A kinematic model of hexapod based on homogeneous matrices was created and verified [4]. The model is convenient in engineering practice.

- A kinematic model of the hexapod in dual quaternions is created. This model has more functionality and computational efficiency.

- Various gaits were synthesized (including one-legged and three-legged). Three-legged gait is the fastest of statically stable gaits. One-leg gait is the most stable. In a one-legged gait, the hexapod has the largest carrying capacity.

- Developed and debugged methods for controlling the motion of the hexapod with a joystick and keyboard, which significantly reduces the complexity of training attendants. Currently, work is underway to create an algorithm for rearranging legs while moving a hexapod through movable obstacles of arbitrary shape.

4. Prospects of the development of the complex
- Due to easy parallelization of experiments, good repeatability and centralized storage of data, the simulator can be adapted for carrying out computationally capacious experiments, such as searching for optimal gaits using genetic algorithms or neural networks.

- When deploying a simulator in a telecommunications network, it becomes possible to attract a large number of operators simultaneously for large-scale research and experiments, to increase the speed of rescue operations, and to conduct various contests and competitions.

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