

Decision-making technology for changing the performance characteristic of the adaptive wheeled movers of complex robotic systems

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Abstract—A solution is proposed for automating the process of controlling the wheel diameter of robotic systems and its main characteristics. Changes in rigidity, contact area with the surface, linear speed, turning radius contribute to higher mobility and increased maneuverability. A decision-making technology for changing the driving characteristics of adaptive propulsion systems has been developed with the focus on the probabilistic approach of estimating the faults of the positioning system modules in space.

Keywords—*decision-making technology; adaptive propulsion systems; complex robotic systems; automated control system; strain measurement, probabilistic approach*

Complex robotic systems (CRS) are utilized in industrial, agricultural, marine, military and live-saving purposes. The main types of propulsion systems are wheeled movers, walkers, caterpillars, anthropomorphic devices, etc. Ideas of using adaptive wheels able to change their rigidity, wheel size, contact area with the surface are increasingly being applied. Integrating adaptive wheels contributes to both higher mobility and increased maneuverability of wheeled movers; and integrating strain gauging enables the creation of automated systems that make decisions on changing the diameter of the wheel for the purpose of its most effective movement based on the geometry of obstacles. The automated system for controlling adaptive propulsion devices is able to reserve technological vision in case of their failures [1].

Adaptive propulsion systems (wheeled movers) are utilized in vehicles, in complex robotic systems for ground and space purposes, in marine robots used for the exploration and offshore production of hydrocarbons, as well as in seafloor mapping. Nowadays, seafloor exploration is considered one of the global tasks of high priority ranged from mineral exploration and seabed mining to pipe-laying at great depths. Wheeled robots are most often used in cartographic exploration. Complex seafloor landscapes and problems related to signal transmission prove the necessity of adaptive propulsion systems which can sense any obstacle and change the parameters of the wheel in order to get over this problem area without human aid. Operations of designing and creating

adaptive wheels contribute to both higher mobility and increased maneuverability of wheeled movers [2].

The purpose of this study is to enhance the reliability of CRS's positioning control system. To accomplish the aforementioned purpose, the following tasks should be solved:

- to discuss possible causes of CRS positioning failures;
- to develop a life-cycle model in the form of a transition graph;
- to develop an algorithm for automatic control of the parameters of the wheel with regard to the landscape moved across;
- to develop a decision-making technology focused on changing the driving characteristics of CRS's adaptive propulsion systems.

To reveal any possible failure area of the CRS positioning system in space, let us consider the proposed design of the adaptive wheel (Fig.1) equipped with strain sensors for defining the stress-strain state of the elastic-metal body [3].

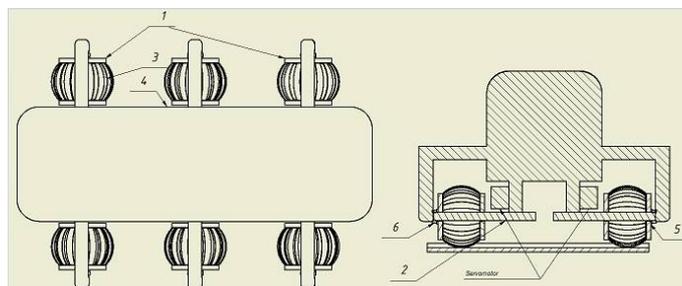


Fig.1. Virtual model for adaptive wheels of complex robotic system (lhs. - top view, rhs. - cross-sectional view)

The adaptive wheel comprises the following parts: 1 – a hub fixed to axle 2 that transmits driving torque to the wheels (each wheel is driven by its own servomotor); 3 – an elastic metal body made of elastic plates with strain sensors on their inner sides; 4 – a robot body; 5 - fixtures; 6 – outer hubs. Inner hubs located closer to the body are moved by a servomotor.

Each wheel has its own actuator, which allows moving at a constant speed and in a straight line, for different diameters of the wheel (for example, when only one side of the robot is passing the obstacle). The calculator mechanisms are located on the hub inside the wheel [4].

To conduct the calculation and investigation procedures, it was assumed that the plates were absolutely elastic, the robot moved along a regular geometrically flat surface, and the obstacles were square-shaped steps; the coefficient of friction with the soil was recognized as constant [5].

The working principle of the adaptive wheel was as follows: bending resistors were fastened to each elastic wheel plate, on the inner sides. The resistors were bailed in such a way that the plate under no load would demonstrate resistance taken as the reference value, and the plate under load would have a smaller resistance. The sensor readings were transmitted to a microprocessor, which made a comparison and determined the location of the contact with the surface and other plates for the purpose of detecting the obstacle. If the resistance of the strain sensor on the plate decreased after contact with the ground, it would be necessary to increase the radius of the wheel because of the obstacle. The signal from the microprocessor was fed to the servomotor, which, in turn, by means of a gear transmission, moved the hubs from the inner side of the CRS [6].

Let's consider the block diagram for the CRS positioning system module failures (Fig.2).

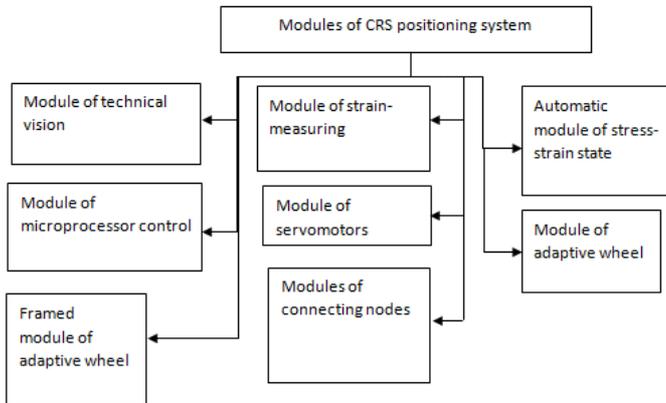


Fig. 2. Block diagram of failures of the CRS positioning system modules

To determine the probabilities of robotic system functioning in a particular phase (situation), a life-cycle model was used in the form of a transition graph (Fig. 3).

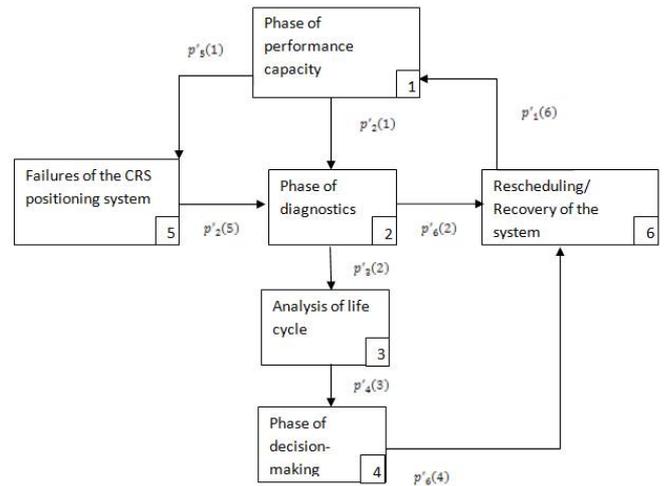


Fig.3. Life-cycle model in the form of a transition graph

The conditional probability of CRS functioning in the operational phase:

$$P_1 = \frac{p'_{1(6)}}{1 + \sum_{k=0}^{T-1} p'_{1k}(k-1)} \tag{1}$$

Where T = 6 - total number of phases (situations);

- phase of diagnostics:

$$P_2 = \frac{p'_{2(1)} + p'_{2(5)}}{1 + \sum_{k=0}^{T-1} p'_{2k}(k-1)} \tag{2}$$

- analysis of the life cycle of the CRS:

$$P_3 = \frac{p'_{3(2)}}{1 + \sum_{k=0}^{T-1} p'_{3k}(k-1)} \tag{3}$$

- phase of decision-making:

$$P_4 = \frac{p'_{4(3)}}{1 + \sum_{k=0}^{T-1} p'_{4k}(k-1)} \tag{4}$$

- failures of the CRS positioning system:

$$P_5 = \frac{p'_{5(1)}}{1 + \sum_{k=0}^{T-1} p'_{5k}(k-1)} \tag{5}$$

- rescheduling and recovery of the CRS positioning system:

$$P_6 = \frac{p'_{6(2)} + p'_{6(4)}}{1 + \sum_{k=0}^{T-1} p'_{6k}(k-1)} \tag{6}$$

On the basis of possible failure points in the positioning system, a decision-making technology for changing the driving characteristics of the adaptive propulsion devices of robotic systems was developed (Fig. 4).

$$\alpha_1 = 360/n \quad (10)$$

Thus, the angle between the radius of the wheel and the contour line at the point of contact with the obstacle is:

$$\varphi_1 = 180 - \alpha_1 - 90 \quad (11)$$

Or in case of "collision with an obstacle" of the "b" plate:

$$\varphi_n = 90 - h\alpha \quad (12)$$

Due to the geometry of the triangle AB1C1:

$$\sin(\varphi_n) = \frac{((r+h_s)-k_n)}{r+h_n} \quad (13)$$

Where r - radius of the hub (used for the convenience of calculations). Then, the height "n" of the obstacle is calculated as:

$$k_n = h_s + r(1 - \sin(\varphi_n)) - h_n \sin(\varphi_n) \quad (14)$$

The conditions of getting over an obstacle is:

$$k_n \leq \frac{1}{2}d \quad (15)$$

Then, the new minimum diameter is determined:

$$d_{new} = 2k_n \quad (16)$$

It should be noted that any change in diameter leads not only to increased maneuverability, but also to a decrease in the area of contact with the ground and, respectively, to the possibility of increasing the linear speed of movement and maneuverability by varying the turning radius of the robotic system [8].

During the diagnostics of the wheel, a constant comparison is made between the given reference deflection values, the elastic generators of the wheel frame and the obtained values from the sensors. If the deflection is long (above the critical norm), the time is also set by the operator, the microprocessor determines that the wheel is damaged, and it is necessary to redistribute the arrangement of the propellers to eliminate the displacement of the center of the CRS mass. Also, a warning about the damage of the propeller takes place and it is switched to passive rotation; extra reduction of the diameter is also possible to prevent a negative impact on neighboring wheels. The second reason for the smaller diameter of the damaged wheel is the removal of "the hooks" with the ground.

Diagnostics of the state of adaptive propulsors has a constant feedback, by which the constant control of the

condition of CRS propellers is carried out and decisions are made in regard to any changes in its driving characteristics.

In order to ensure a reliable operation of the CRS, it is necessary to provide the announced working efficiency to its every module. In this case, working mode selection conditions can be considered with due regard to the probability of its functioning in this or that life-cycle phase. To increase the wear resistance and reliability of the most loaded moving parts (for example, coupling of servomotors, wheel shaft, bearings, etc.), it is proposed to use wear-resistant powder composite materials applied to the part by the method of gas-thermal coating. This allows extending the life cycle of the CRS.

CONCLUSION

The developed decision-making technology for changing the driving characteristics of adaptive propulsors, taking into account the functioning in different phases of the life cycle, makes it possible to increase the survivability and maneuverability of robotic systems of various types.

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