Formulation of the Optimization Problem of the Cyber-Physical Diagnosis System Configuration Level for Construction Mobile Robots

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Abstract –

This article studies the development of a cyber-physical prediction diagnosis system for electric drives of the construction robots. The structure of the five level diagnosis cyber-physical system is described. The optimization problem with the configuration level of the cyber-physical diagnostic system is formulated.The problem of determining the optimal trajectory for a mobile construction robot taking into account the wear of its electric drives is presented. As an example, a construction four wheels mobile robot with a differential drive is considered. The task of the robot is the alignment of the construction site, which involves its sequential bypass. From the standpoint of wheels drives wear, the trajectory is considered optimal if the robot makes approximately equal number of right and left side turns. To design a mathematical model for optimal trajectory determination, graph theory and probabilistic algorithms is proposed. The presented model does not take into account the soil structure and the working space inclination.

Keywords –

Cyber-physical diagnosis system; Building robots; Electric drives; Optimal trajectory; Wear

1 Introduction

Reliable construction work entails the need for continuous monitoring of the technical condition of all its actuators with further optimization of their mode of operation and consequently of the entire technological process as a whole. This can be achieved by using a technical condition monitoring system built into the robot's end-effectors, which continuously measures parameters and analyzing the information obtained and determining the current and future technical condition, and optimizing the parameters of the object's operation mode. Implementation of this approach assumes the integration of computing resources into physical processes, i.e. application of cyber-physical systems [1]. In such systems includes, sensors, mechanical equipment and information systems are connected during all stages of the life cycle and interact with each other using standard Internet protocols. This allows to predict and adapt to changes in operating conditions and technical condition of the equipment. The structural scheme of the cyber-physical predicting diagnosing system of the construction robot is shown in Figure 1.

The cyber-physical predicting diagnosis system has five levels: connecting, conversion, cloud, cognition and configuration [2].

At the “Connection” level, an effective set of diagnostic parameters and the sensors for its measurement are selected. The sensors should be designed for self-connection and self-monitoring of the state of the object.

At the "Conversion" level, the values of diagnostic parameters are measured and their necessary transformations in the case predicting diagnostic methods.

Storage and processing of large amounts of diagnostic information is carried out in cloud servers. This will allow the information flow and communication between the drives of various construction robots. Based on that, the optimization of the technological process starts taking into account the state of a separate actuating element.

At the “Cognition” level, methods of diagnosing and forecasting the technical condition of construction robots drives are chosen [3].

These methods must meet the following requirements:

– the possibility of assessing the technical state in real time; minimum composition of the measured parameters;

– the absence of complex bulky measuring equipment installed on the drive housing, which can affect the operation of process equipment;

– possibility to use on a moving object with high humidity and dustiness; applicable for DC and AC motors;

– the ability to automatically analyze the measured parameters;

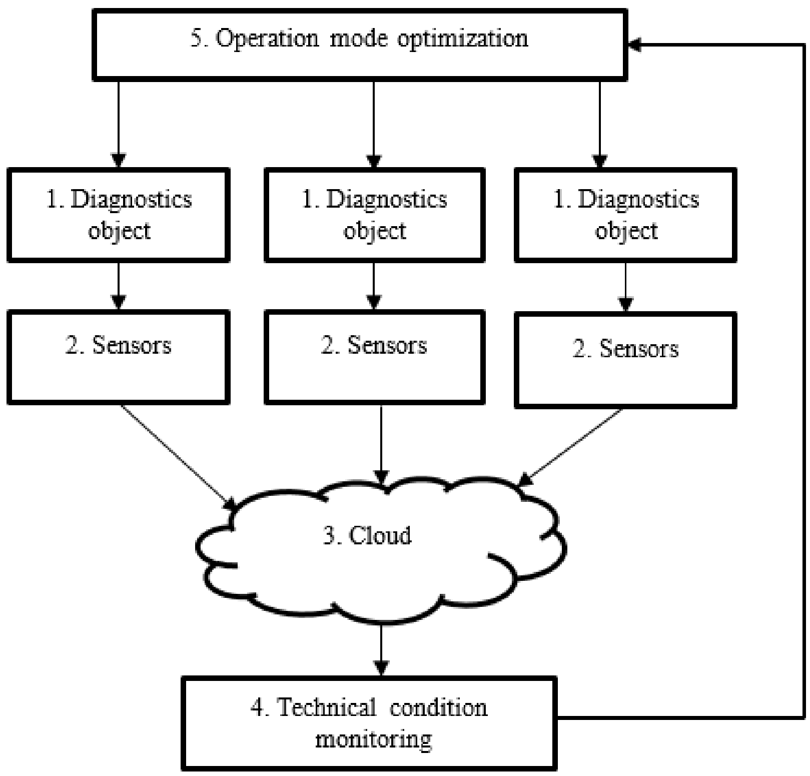

Figure 1. Cyber-physical system of the technical condition prediction diagnosis for electrical drives: 1– Intelligent connection level; 2–Data conversional level; 3–Cloud level; 4–Cognitive level; 5– Configuration level

– the ability to distinguish a malfunction from a change in operating mode; the ability to record and store diagnostic results in a cloud server and to provide the user with an Internet protocol.

The results of diagnostics and forecasting are presented to users and transmitted to the mathematical model of the object for further optimization of the robot operation mode.

At the "Configuration" level, the operation of the diagnostics object is optimized.

Construction robots operate in complex non-deterministic conditions with high alternating loads in conditions of high humidity and dust. Their drives are often installed on a mobile base, which imposes significant requirements for the choice of methods and means of diagnosis such as:

– minimum composition of the measured parameters;

– the absence of complex bulky measuring equipment installed on the drive housing, which can affect the operation of process equipment;

– the automatically analyze the measured parameters.

Analysis of the majority of electrical and mechanical faults of the electrical drive can be detected by monitoring the supply and capacitive current, which can be measured without the use of special sensors.

For the "Cognition" level, a method for diagnosing electric drives of building robots has been obtained [4], which makes it possible, without using expensive measuring instruments, to determine their current state of failure, a malfunction from changing the operating mode. This will increase the efficiency of such robots and the quality of construction operations.

The main part of the cyber-physical system is the "Configuration" level. It implements the task of optimizing the work of construction robots according to the results of diagnosing the technical condition of their electric drives.

After the technical condition of each electric drive of a construction robot is determined, it is necessary to optimize the operating mode of robots in order to increase the equipment life. Significant impact on the electric motor life have loading conditions during operation. The diagnosis will significantly extend the uptime of the electric drive and all equipment as a whole. To solve the increasing the reliability of the electric motor problem separate from the object where it is installed without taking into account the operation of all other mechanisms is impossible. Therefore, this problem should be solved in a group of drives of an object operating in a certain technological process.

As an example, consider a mobile construction robot used to level the construction site. Tit have four independent electric drives, which are a mechatronic module “motor-wheel” [5]. The task of the robot is to handle rough terrain of a given geometry. In this case, the choice of the trajectory of the robot should be carried out in such a way that the wear of the drives of its wheels was minimal.

2 Robot Wear Model

Consider a model of a four-wheeled mobile robot with a differential drive (Fig. 2). It is assumed that the robot is driven in one of three ways:

1) using the wheels D^1 and D^2 (front wheel drive);
2) using the wheels D^3 and D^4 (tasks drive);
3) using all four wheels simultaneously (all-wheel drive).

The preferred option for controlling, all-wheel robot drives, since the life of the wheel drive is consumed evenly. However, in the event of a failure of one of the engines, the control system can be returned to the front or rear wheel drive.

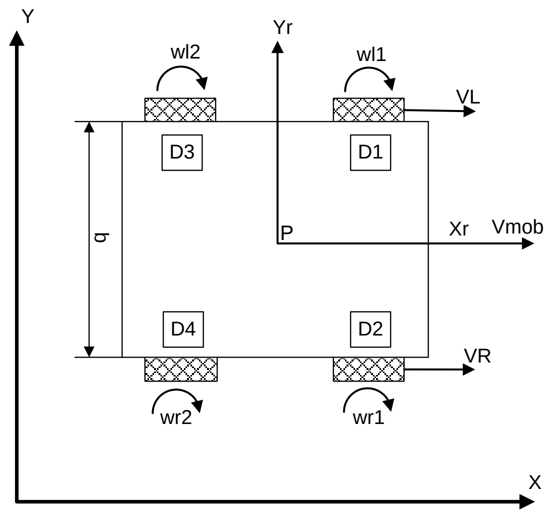

Figure 2. Model of a four-wheeled mobile robot with differential drive

A complete failure of a mobile robot will be considered to be options for working on the right or the left pair of drives (D^1 and D^3 or D^2 and D^4 in Figure 1) or on any one drive, as this leads to a situation of uncontrolled movement of the robot and unreasonable wear of working engines. The degree of wear of the robot is the sum of the degrees of wear of the drives of each wheel when performing a single technological operation t_i (1).

$$P(t_i) = p^1 + p^2 + p^3 + p^4, \qquad (1)$$

where p^1, p^2, p^3, p^4 is the degree of wear when performing a single technological operation of the drives D^1, D^2, D^3 and D^4, respectively.

The wear of the electric drive of each wheel is determined as a function of three arguments (2):

k_{ground} – the soil properties variable (takes on the values: 1 - smooth hard soil, 2 - smooth loose soil, 3 - uneven loose soil);

t_{fun} – the electric drive mode operation variable (0 - passive, 1- “full drive” mode, 2 - active front or rear drive mode);

M_{turn} – the additional motor load variable in a turn (for drives D^1 and D^3 - the right turns, for D^2 and D^4 - the left turns).

$$\begin{cases} p^1 = f(k^1_{ground}, t^1_{fun}, M^1_{turn}), \\ p^2 = f(k^2_{ground}, t^2_{fun}, M^2_{turn}), \\ p^3 = f(k^3_{ground}, t^3_{fun}, M^3_{turn}), \\ p^4 = f(k^4_{ground}, t^4_{fun}, M^4_{turn}). \end{cases} \qquad (2)$$

3 The Optimization Problem Formulation

For experiments in the proposed model of wear, the following restrictions are introduced:

1) the robot moves on a horizontal working space (Z=const);

2) the robot moves at approximately constant speed (V=const).

The trajectory of the robot is selected depending on the configuration of a specific construction site. Examples of their forms are shown in Fig. 2

t_0	t_1	t_2	t_3
t_4	t_5	t_6	t_7
t_8	t_9	t_{10}	t_{11}
t_{12}	t_{13}	t_{14}	t_{15}

a)

t_0	t_1	t_2	
t_3	t_4		
t_5	t_6	t_7	
t_8	t_9	t_{10}	t_{11}
t_{12}		t_{13}	t_{14}

b)

Figure 3. The examples of the construction robot working space

The robot working space being processed is divided into n segments so that each of them uniquely defines the limits of a single technological operation t_i (i = 1..n) .

For processing of construction sites (Fig. 3), it is necessary to set a complex trajectory of movement taking into account the wear of its electric motors.

The task of the robot is to fully implement the technological process (performing all its technological stages) so that the total wear of P_0 electric drives is minimal (3):

$$P_0 = \sum_{i=1}^{n} P(t_i) \rightarrow \min . \quad (3)$$

The wear P_0 is assumed to be minimal when it is evenly distributed between the drives D^1, D^2, D^3 and $D^4$is accepted. It is possible to reach with the minimum difference between the right ($M_{turn(R)}$) and left ($M_{turn(L)}$) turns (4):

$$\sum M_{turn(R)} - \sum M_{turn(L)} \rightarrow \min . \quad (4)$$

If for a particular construction site all its n segments are represented as the corresponding graph *T (V, E)*, the set of vertices *(V)* uniquely corresponds to the field segments, and the set of edges *(E)* logically defines possible transitions between adjacent segments (technological operations), then the mathematical problem of synthesizing the effective trajectory $G(P_0)$ for processing the construction site can be represented as follows (5) [6,7]:

$$G(P_0) = \left\{ t_i \,\middle|\, f(t) = \sum_{i=1}^{n} P(t_i) \rightarrow \min, i = 1...n \right\},$$
$$Z = \text{const}, \quad (5)$$
$$V = \text{const}.$$

The graph representation options for partitioning the working space of the robot (Fig. 3) are shown in Figure 4 accordingly.

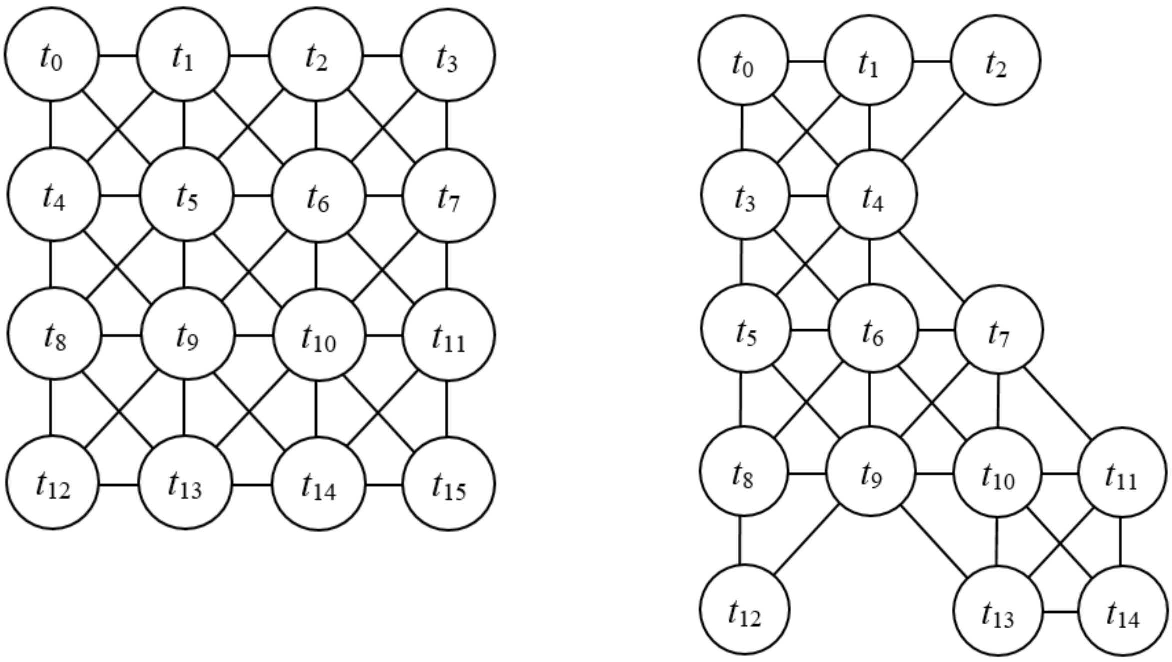

Figure 4. Variants of the graph representation of the robot workspace

Possible solutions for the cases considered from Fig. 3a and Fig.3,b are followed:

– $G(P_0) = \{t_0, t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8, t_9, t_{10}, t_{11}, t_{12}\}$

– $G(P_0) = \{t_0, t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8, t_9, t_{10}, t_{11}, t_{11}\}$

To demonstrate the turns within the selected trajectories the turn matrixes $G(M_{turn})$ is defined,

where 0 - turn within t_i (not performed),

1 - right turn $(M_{turn(R)})$,

2 - left turn $(M_{turn(L)})$.

Then the matrix $G(M_{turn})$ for each of the four previously defined trajectories will take the following form:

1st trajectory:

$G(M_{turn})$ = {0,0,0,1,1,0,0,2,2,0,0,1,1,0,0,0};

2nd trajectory:

$G(M_{turn})$ = {0,0,1,1,2,0,0,2,2,1,1,0,2,2,0}).

The selected trajectory can be considered optimal from the standpoint of minimizing engine wear if the number of left and right turns for the indicated options of trajectories $G(P_0)$ approximately coincides.

For solving the formulated problem and the need to solve it based on probabilistic algorithms (for example, agent metaheuristics). [8-10]

4 Conclusion

In this paper, the design of a cyber-physical system for diagnosing and predicting the technical condition of electric drives of construction robots is presented. Furthermore, the structure of the cyber-physical system consisting of five levels is defined and the work of each system level is also described. The optimization problem with the configuration level of the cyber-physical diagnostic system is formulated. The problem of determining the optimal trajectory for a mobile construction robot taking into account the wear of its electric drives is presented. From the standpoint of wheels drives wear, the trajectory is considered optimal if the robot makes approximately equal number of right and left side turns. To design a mathematical model for optimal trajectory determination, graph theory and probabilistic algorithms is proposed. The presented model does not take into account the soil structure and the working space inclination.

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