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The Application of Simulation Methods for Modeling Mechatronic Systems

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BIOGRAPHICAL NOTES

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KEY WORDS

Simulation methods, modelling

ABSTRACT

Computer-aided modelling of kinematics and dynamics of robots is an important integrated part within the frame of a modern approach to the design of technical subjects (machines, apparatuses, motor-cars, planes, etc.). It is possible to verify a large spectrum of applications, which can be typical for operation of the simulated subject. Application of the simulation methods enables to accelerate a development process and to improve design of the wheel undercarriage structures of mobile robots.

1. Introduction

A complex understanding of technical subject and computer-aided simulation is one of the main characteristic features of the mechatronic approach to the design of modern products. There are integrated in the simulation model the mechanical, electrical and control subsystems and in this way can be obtained information about mutual interactions among these individual subsystems.

In the case of simulation model of a mobile robot equipped with the sectional undercarriage it is useful to apply methods of kinematic analysis and synthesis of bonded mechanical systems. A functional model of the wheeled robot, which is created afterwards, has a better manoeuvrability during movement across obstacles in a terrain, thanks to a hinge, which is installed in the middle of the undercarriage. The functional model enables also to perform verification of results obtained by means of the simulation experiments.

2. Creation of Mobile Robot Simulation Model

The matrix arithmetic is applied in the area of mechanism kinematics preferably instead of the classic vectorial analysis. From this reason the vectors and vector operations (sum of vectors, scalar product and vector product) are presented in the form of a matrix or matrix operations [1].
Computer-aided simulation of kinematics and dynamics of mechanisms is an important integrated part of the modern approach to the design of technical subjects (machines, apparatuses, motor-cars, planes). Deformations of individual parts of the mechanisms can be neglected in a great number of practical tasks and that is why it is possible to apply the so-called system of rigid bodies with mutual interrelations.

Many principles of kinematics and dynamics of the three-dimensional mechanisms are very complicated to be understood without a necessary theory. Transition from the planar tasks to the spacial problems means a completely new solution level.

In order to assembly the simulation model of the mobile robot there were applied the transformation matrixes. This simulation model describes positions and velocities of the individual wheels. To find out directly the matrix of directional cosines and radius vectors of the coordinate origin is a very difficult question in general. However, if the complex movements are disintegrated into the individual sequences of simple, basic steps, so the solution process can be simplified efficiently. Such disintegration is a standard part of all tasks concerning movement of bodies, practically. The so-called method of matrix kinematics is a very efficient and general method for solution of body movements and for all branch of kinematics, actually [2].

Application of the coordinate system instead of the body for definition of the positions and orientations is a more accurately method. The coordinate system can be connected directly with the body or not. The homogenous coordinates are applied for a simplification of operations with bodies in the three-dimensional space [3, 4].

For the mathematical description of a serial kinematic chain is best to use denavit-hartenberg principle of deployment of joint chain to the coordinate system [10].

The proposed four-wheel undercarriage will be steered differentially. Each of the wheels is driven individually by means of the servomechanism. This is a proposed design solution of the wheeled undercarriage [5]. In the middle-point of the undercarriage is situated a hinge, which enables tilting of both parts of the mobile robot and in this way it increases stability of the robot in terrain.

Fig. 1: *Mobile robot with sectional undercarriage.*

Individual transformation matrixes among the neighbouring local coordinate systems will be multiplied symbolically using the software Mathcad in order to obtain the global transformation matrix, which describes the geometrical position and orientation of the centre of gravity in the global coordinate system, as well as there are obtained in this way the transformation matrixes describing the position and orientation of the individual undercarriage wheels.

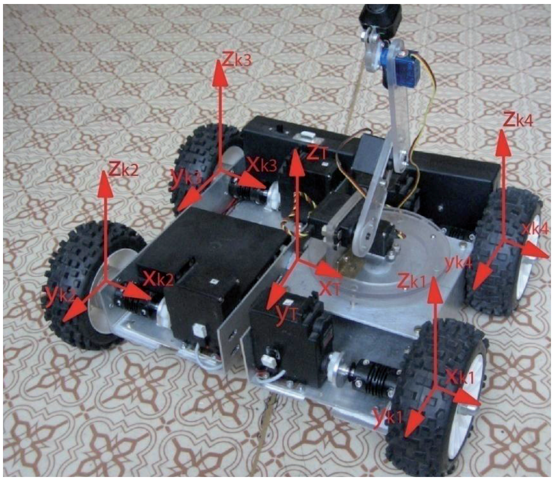

Fig. 2: *Local coordinate systems.*

After derivation of transformation matrixes are obtained relations that are valid for velocity of the undercarriage centre of gravity and velocities of the individual wheels. These derivations are application results of a matrix differential operator [7, 8].

The coordinate q1 represents a transformation of geometrical position of the gravity centre. This transformation corresponds to the rotation around the axis z. The coordinate q2 represents a transformation corresponding with translation toward the axis x.

According to the principle of the differential steering it is evident that if there is actual a requirement of a linear movement, so it is necessary that the turning radius is approximating to infinity. In this case this radius is given by the coordinate q1, which has to approximate to infinity. There was chosen also the third coordinate – q3, which represents transformation of a translation along the y-axis. This coordinate ensures the linear movement of the undercarriage, as well as it simplifies the control of movement and calculations.

The kinematic model of undercarriage takes into consideration the real dimension of the robot. During creation of transformation matrixes for the individual wheels of the undercarriage is used also the 4th coordinate (q4), which takes into account an ability of the undercarriage to be more adaptive during crossing of the surface unevenness. The undercarriage consists of two parts jointed in the centre of gravity by means of the passive hinge, which is able to rotate around the x-axis. Because the hinge is situated in the undercarriage centre of gravity, the magnitude of rotation, which is given by the coordinate q4, will be transferred only in a half-magnitude, i.e. as q4/2.

The final transformation matrix, which describes the position and rotation of the centre of gravity in relation to the global coordinate origin, is:

$$Tt(q1,q2,q3)=\begin{bmatrix}\cos(q1) & -\sin(q1) & 0 & q2.\cos(q1)-q3.\sin(q1)\\ \sin(q1) & \cos(q1) & 0 & q3.\cos(q1)+q2.\sin(q1)\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

The transformation matrix, which describes the position and slewing of the wheel No.2 in relation to the 0 (virtual centre of rotation), defines the equation (2).

$$T_{pw2}=\begin{bmatrix}\cos(q1) & -\cos(\frac{q4}{2})\sin(q1) & \sin(\frac{q4}{2})\sin(q1) & 175.\cos(q1)-95.\cos(\frac{q4}{2})\sin(q1)+q2.\cos(q1)-q3.\sin(q1)\\ \sin(q1) & \cos(\frac{q4}{2})\cos(q1) & -\sin(\frac{q4}{2})\cos(q1) & 175.\sin(q1)+95.\cos(\frac{q4}{2})\cos(q1)+q3.\cos(q1)+q2.\sin(q1)\\ 0 & \sin(\frac{q4}{2}) & \cos(\frac{q4}{2}) & 95.\sin(\frac{q4}{2})\\ 0 & 0 & 0 & 1\end{bmatrix}$$

The positions and slewing of the rest three wheels can be expressed analogically. The resulting transformation matrixes are applicable for various dimensions of the undercarriages that are based on the same principle conceptually.

Using derivation of transformation matrixes are obtained relations for velocity of the undercarriage centre of gravity and velocities of the individual wheels. These derivations are application results of a matrix differential operator.

Velocity of the wheel No.2 can be written in the form:

$$T_{vw2}=\begin{bmatrix}-\sin(q1) & \sin(q1)\sin(q3)-\cos(q1)\cos(q3) & \cos(q1)\sin(q3)+\cos(q3)\sin(q1) & -94.\cos(q1)-176.\sin(q1)-q3.\cos(q1)-q2.\sin(q1)\\ \cos(q1) & \cos(q1)\sin(q3)-\cos(q3)\sin(q1) & \sin(q1)\sin(q3)-\cos(q1)\cos(q3) & 176.\cos(q1)-94.\sin(q1)+q2.\cos(q1)-q3.\sin(q1)\\ 0 & \cos(q3) & -\sin(q3) & -\sin(q3)\\ 0 & 0 & 0 & 1\end{bmatrix}$$

Velocities of other wheels are obtained in the same way.

The simulation models that are required for determination of geometrical position and velocity of undercarriage centre of gravity and wheels can be created by means of the defined transformation matrixes using the software product Matlab/Simulink.

3. Simulation of Undercarriage Model Behaviour

The simulation of behaviour of the undercarriage model is useful for testing of its behaviour in various standard and non-standard situations.

Movement of the undercarriage forwards and backwards is often a standard situation, which is used during locomotion of the undercarriage in a terrain. It is the simplest motion realized linearly.

The linear movement along the y-axis is investigated in the next simulations.

Typical situation is such that the undercarriage is moving in the distance 1500 mm from the virtual centre of rotation. During a simulated movement forwards the change of position of the undercarriage and wheels is the same due to construction of the undercarriage.

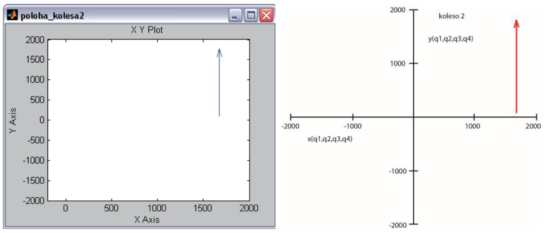

Fig. 3: *Position of the wheel No.2 using the software Matlab and Mathcad.*

Velocity simulations of the undercarriage centre of gravity and wheels in the directions forwards and backwards can be realized analogically. The normal undercarriage velocity is 100 mm/sec.

In the Fig.4 is illustrated the time behaviour of the velocity for the wheel No.2 during the linear movement forwards.

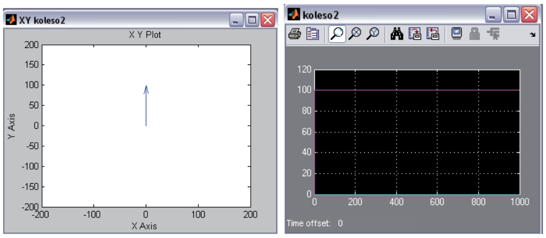

Fig. 4: *Behaviour of the wheel No.2 velocity during movement forwards using the Matlab software.*

The final magnitude of the velocity vector for the wheel No.1 during movement forwards is:

$$v_2 = \sqrt{v_{x2}^2 + v_{y2}^2 + v_{z2}^2} = \sqrt{0^2 + 100^2 + 0^2}$$

$$v_2 = 100 mms^{1}$$

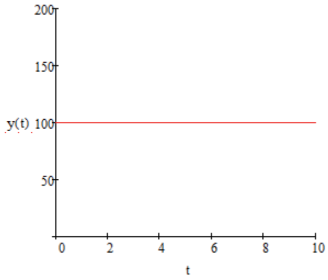

Fig. 5: *Time behaviour of the wheel No.2 velocity during movement forwards using the Mathcad software.*

The velocity of the wheel No.2 during a linear movement forwards is identical with the velocity of the undercarriage centre of gravity, as well as it is identical with the velocities of the other wheels according to the simulated situation of a linear movement forwards with the constant speed.

Simulation results for the linear movement forwards were verified on the real model GTR2010.

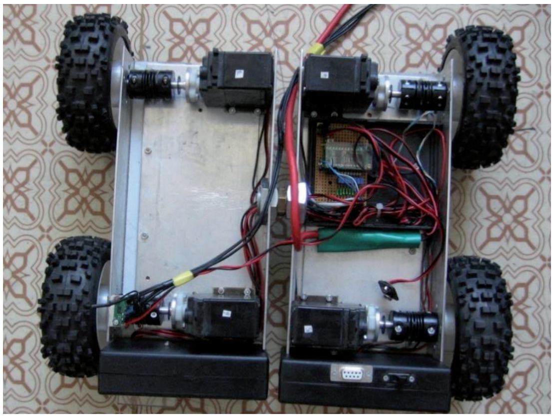

Fig. 6: *Mobile chassis GTR 2010*

There is presented in the Fig. 7 position of the wheel No.2 and in the Fig. 8 is illustrated time behaviour of the wheel No.2 velocity, which is based on data obtained from the 3-axial accelerometer. According to the Fig. 7, the change of the wheel No.2 position along the y-axis is changing linearly, i.e. the undercarriage is moving forwards in the linear direction. This result confirms also the record of the undercarriage position, which was obtained during the simulation (Fig.3).

The velocity of the wheel No.2, which was obtained experimentally, corresponds also with the result of simulation. The lower values at the beginning of experiment are caused due to acceleration phase, as well as because there is not applied a control system. From this reason the start-up phase is longer.

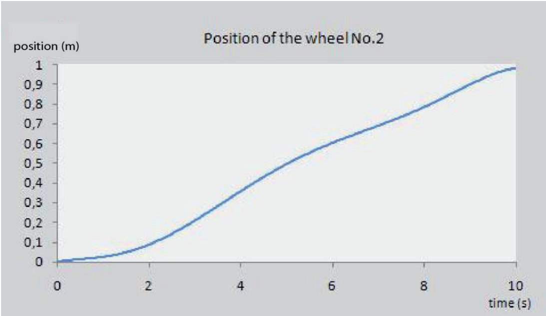

Fig. 7: *Position of the wheel No.2 obtained experimentally.*

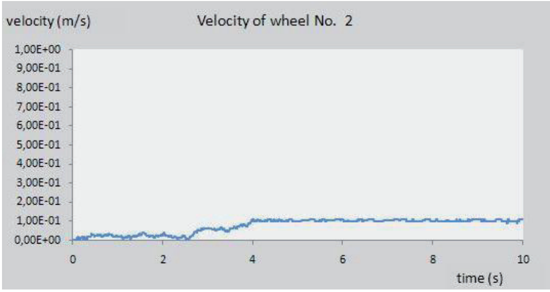

Fig. 8: *Velocity of the wheel No.2 obtained experimentally.*

4. Conclusion

Thanks to the simulation software products it is relatively easy to fulfil requirements without a necessity to design a real physical model, or there is also another advantage that the real equipment cannot be damaged during testing. After verification of the simulation model is possible realisation of the real functional mechanism.

The created simulation model can be applied for calculation of assumed or intended path of the undercarriage centre of gravity and path of wheels. It offers a possibility to analyse impacts of terrain unevenness on behaviour of the undercarriage mechatronic system.

The simulation model was elaborated by means of the software application Matlab/Simulink, as well as using the Mathcad simultaneously.

5. Acknowledge

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