Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 177 (2017) 162 – 167

Procedia Engineering

www.elsevier.com/locate/procedia

XXI International Polish-Slovak Conference “Machine Modeling and Simulations 2016”

Dynamics model of the mobile platform for its various configurations

Anna Jaskot, Bogdan Posiadała*, Szczepan Śpiewak

Institute of Mechanics and Machine Design Foundations, Czestochowa University of Technology

Abstract

Description of the dynamics of the four-wheeled mobile platform has been proposed in the paper. Proposition of different configurations of load with consideration of distribution of load to each wheel of the mobile platform is presented. The prototype model is useful to examine different configurations of the drive wheels and to analyse the relations between causes and effects of the motion parameters. The problem of the forced motion of the platform, with the possibility to modify the drive modulus positions, has been considered. The various configurations of the driven wheels, which has significant influence for both the position of the center of mass and the distribution of load acting on the wheels, is presented in the work. The formulated initial problem has been solved numerically with use of the Runge-Kutta method of the fourth order. The analysis of several sample results for the different positions of center of mass has been conducted and the conclusions are also included.

Peer-review under responsibility of the organizing committee of MMS 2016

Keywords: dynamics; mobile platform; load distribution; forces in wheels;

1. Introduction

The objectives in realizing construction of the four wheeled mobile platform cover comprehensive studies of dynamic phenomena that can occur during the mobile platform motion. The research includes in particular the subjects of unsteady motion of the platform under the straight and curvilinear trajectories. The presented project of the wheeled mobile platform will be accomplished in such a way that it will allow the realization of the motion for many possible configurations of positions of wheels relative to the whole vehicle.

* Corresponding author, Tel.: +48 34 325-06-20; fax: +48 34-325-06-47.
E-mail address: bogdan.p@imipkm.pcz.pl

Peer-review under responsibility of the organizing committee of MMS 2016
doi:10.1016/j.proeng.2017.02.211

The realization of proposed research is essential to know the platforms work that has significant meaning for both the optimization of the construction solutions and the selection of the operating conditions for the considered group of machines. Mobile robotics is a field of science, which still grows, hence there are many works in literature, covering the research issues at this point. One of the most often asked questions, considering the mobile platforms, is a description of motion, including the movement parameters, i.e.: coordinates of trajectory, velocity and acceleration of mobile platform and its elements. The works [6] and [2, 3, 10, 12] refer to description of motion of two, three or more than three wheeled mobile robots. The kinematic and the dynamic analysis including the trajectory tracking and path generation for nonholonomic systems are a continually common matter. In previous studies the kinematics of wheeled mobile robots has been the main subject in planning the control of nonholonomic systems. The analysis of motion planning with consideration of the dynamics equations is proposed among others in [11, 13]. Proposition of the trajectory planning problem for multi-objective is widely described in [9]. The formulation of tracking control of a group of mobile robots with guarantee of no collisions between robots is proposed and described in [5]. Approach to the kinematic and dynamic solutions for the possible positions of the wheeled platforms are proposed in [2].

Knowing the differential equations of motion the simple or inverse task of the dynamics can be solved. Due to the complex form of the equations describing the motion of the system in the inverse task of the dynamics, the solution of it can make a problem. This paper presents a solution to the inverse problem of dynamics. The motion parameters can be determined by using the Euler's parameters and Kane's method as described in [1], Maggie equations in [4], Langrange method in [2]. The effect of this is generating and implementing the trajectory of the platforms motion. In this paper the solution with use of the Runge-Kutta method of the fourth order is included.

The design of the mobile platform prototype, with description of the constructional elements is contained in [7].

2. Model of dynamics of the mobile platform

In this section the theoretical and computational models of dynamics of the four-wheeled mobile platform are presented. The previous studies on the kinematics confirmed the correctness of the analysis for proposed solution of the mobile platform.

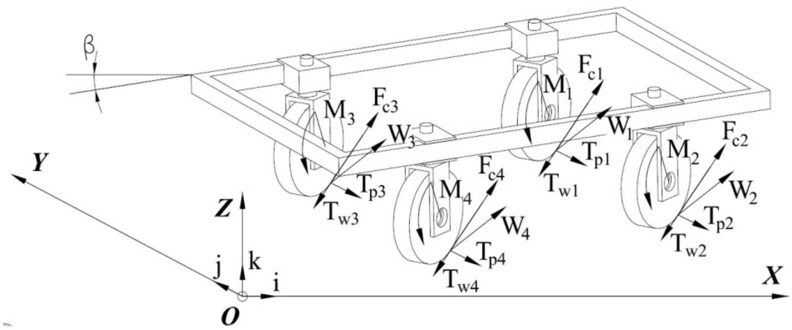


Fig. 1. Force distribution in the mobile platform model.

The model shown schematically in Figure 1 is adopted in order to describe the dynamics of the mobile platform prototype in the configuration coordinate space. The model is built to conduct the analysis of the behavior of the platform when it is subjected to various configuration of load. In Figure 1 the forces occurring during the

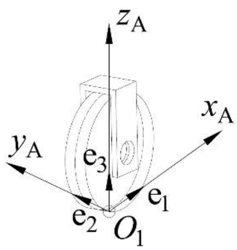


Fig. 2. Representation of local coordinate system for *A* wheel, analogous to each one of the remaining wheels.

platforms motion are presented. This is a schematic model, which represents the motion, where every wheel has an independent drive.

In this paper position of wheels are fixed during the motion, but in further research wheels will rotate freely in order to adjust the current motion of the platform. In Figure 2 the local coordinate system $O_1x_Ay_Az_A$ for *A* wheel is presented. By substituting indexes corresponding to *A* wheel, by indexes from remaining wheels the description for them can be obtained.

The drive torque $\mathbf{M}_i$ represents the movement. The $\mathbf{F}_{ci}$ (i = 1,2,3,4) are the active driving forces (acting on *i*-th wheel), which are deriving from the torque and the size of drive wheel (r – radius of wheel) and calculated by using the formula:

$$\mathbf{F}_{ci} = \frac{M_i}{r} \cdot \mathbf{e}_1^i \tag{1}$$

The $\mathbf{T}_{wi}$ and $\mathbf{T}_{pi}$ symbols represent the friction forces, respectively in the longitudinal and the transverse directions. The $\mathbf{W}_i$ is the resultant force, which replaces the described above forces applied to *i*-th wheel.

The computations are made in reference to the global coordinate system OXYZ. The symbol β represents an angle between the global coordinate X axis and the longer side of the frame. The methodology in determining the dynamics model of the platform is similar to the one described in [8], which concerns the three wheeled mobile platform. The translational motion equation can be formulated in the form:

$$m\mathbf{a} = \sum_{i=1}^{4} \mathbf{W}_i \tag{2}$$

where: m – the mass of the whole object, $\mathbf{a}$ –the acceleration of the centre of mass, $\mathbf{W}_i$ – the *i*-th resultant force.

The equation of the rotational motion around the centre of mass for the platform can be written in the form:

$$\frac{d\mathbf{K}}{dt} = \sum_{i=1}^{4} \mathbf{s}_i \times \mathbf{W}_i \tag{3}$$

where: $\mathbf{K}$ – the angular momentum vector of the whole platform, $\mathbf{s}_i$ (i=1,2,3,4) – the location vectors between centre of mass and points representing wheels positions *A, B, C, D*.

The vectors used in equations can be defined similarly as in [8]. These vectors have the form:

$$\mathbf{W}_i = \mathbf{F}_{ci} + \mathbf{T}_{wi} + \mathbf{T}_{pi}, \tag{4}$$

$$\mathbf{T}_{wi} = -\mu_w \cdot N_i \cdot sign(v_{wi}) \cdot \mathbf{e}_1^i \tag{5}$$

$$\mathbf{T}_{pi} = -\mu_p \cdot N_i \cdot sign(v_{pi}) \cdot \mathbf{e}_2^i \tag{6}$$

where: μ_w, μ_p are the coefficients of friction for the longitudinal and transverse directions and the v_{wi} and v_{pi} are the velocity components for the longitudinal and transverse directions, N_i– reaction deriving from the wheel load on the ground. Reaction force N_i can be designated according to the Eq. (7).

$$\mathbf{N}_i = \mathbf{G}_i \tag{7}$$

where: $\mathbf{G}_i$ is value of load force acting on each wheel ($\mathbf{G}=mg$).

Using equations (1) and (2) the initial problem, by adding the initial conditions according to the starting values of the motion parameters, can be formulated. The solution of the initial problem enables one to determine the motion parameters of the platform under the influence of known external forces.

The dynamics equations of motion can be written in case of the planar motion in the form:

$$\ddot{X} = \frac{1}{m} \sum_{i=1}^{4} W_{ix} \tag{8}$$

$$\ddot{Y} = \frac{1}{m} \sum_{i=1}^{4} W_{iy} \tag{9}$$

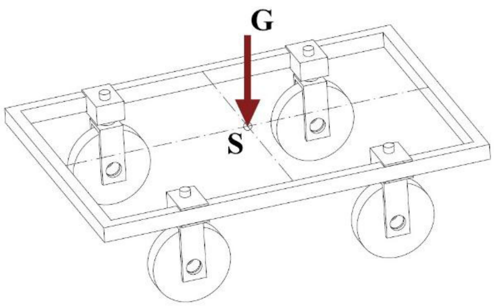
$$\ddot{\beta} = \frac{1}{I_z} \sum_{i=1}^{4} (s_{ix} \cdot W_{iy} - s_{iy} \cdot W_{ix}) \tag{10}$$

In this paper, based on the formulated initial problem, the analysis of the influence of different load configuration on the platform motion is completed. The configurations are described in the next section.

3. Load configurations and mass distribution on the mobile platform

Considering the mobile platform motion, taking into account the use of such machines (most often the handling systems and transport between operations), to properly distribute the load to each one wheel, the classical methods were used. The mobile platform has been undertaken as a spatial system, and the total mass was divided proportionally to every wheel of the mobile platform. In the paper two configurations of possible load distributions are presented.

1˚ 2˚



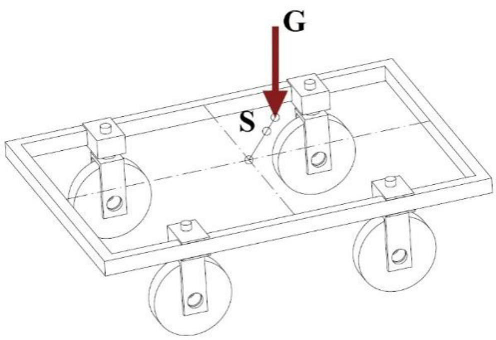


Fig. 3.Possible configurations 1-2 of applied load to the mobile platform prototype.

The presented in Figure 3 possible configurations are described below.

1˚ load located in the middle of the platform, in the platforms center of gravity.

2˚ load located in any position (for the purpose of the analysis in generating results the load were located in front of the platform), near to the A wheel, as is shown in the Figure 3.

The results of the analysis are presented in next chapter.

4. Sample results of the dynamic motion parameters

The sample simulation results has been obtained with the following assumptions. The drive torque M_1=2 Nm, coefficients of static friction in the longitudinal direction μ_w=0.1 and in the transverse direction μ_p=0.1, mass of the platform, m=150 kg (sum of external mass equals 50 kg and mass of the platform equals 100 kg), the of gravitational acceleration g=9.81 m/s^2, and the angle β=0˚. Parameters have been determined by using Runge–Kutta method of the fourth order. Considerations contain the straight–line trajectory motion.

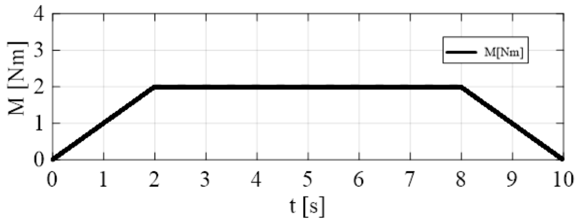


Fig. 4.Drive torque representation during the platforms motion.

The description of the dynamics has been drawn up with assumption that the drive torque is given as a trapezoidal function as shown in Fig. 4.
For the configurations described in section 3, the results are presented separately.

1˚ load located in the middle of the platform, in the center of gravity of the platform

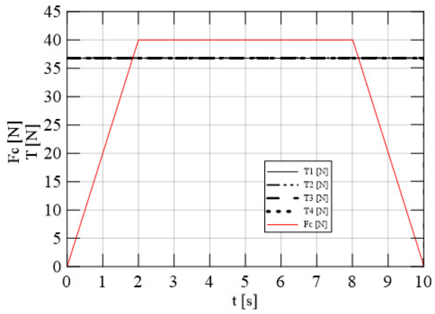


Fig. 5.Relation between the active force Fc and the friction forces for each wheel of the platform.

In the Figure 5 the representation of the forces is posted. Positioning the external load in the center of the platform resulted in that values of the considered longitudinal friction forces are equal for every wheel of the platform. The motion parameters are presented in Figure 5. In the first case the total mass of the platform was distributed equally to each wheel, so *m*/4=150/4 kg. The motion parameters for every wheel in this situation are similar.

2˚load located in front of the platform, near to the A wheel

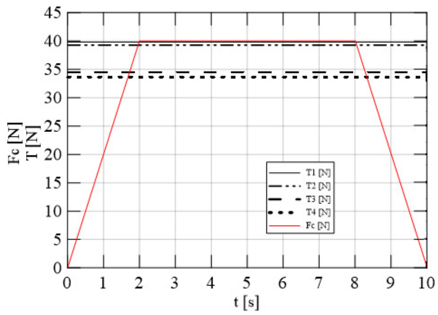


Fig. 6.Relation between the active force Fc and the friction forces for each wheel of the platform in second load configuration.

In Figure 6 the values of friction forces for every wheel are presented. Because of the not-centered load placement, the values are different for each other. *T1* line is representing the friction force for A wheel, and because the load is placed in the nearest neighbourhood of A wheel, the value of the friction force for A wheel is the biggest. The further from load position the wheel is, the value of friction force is smaller.

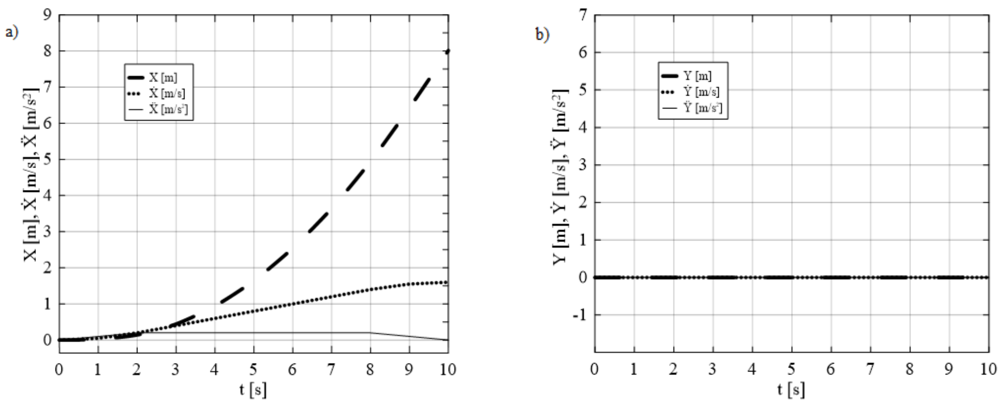


Fig. 7.Motion parameters for center of mass of the mobile platform a) on the X-axis direction, b) on the Y-axis direction.

The values of the motion parameters for the center of mass of the mobile platform for the undertaken assumptions are presented in Figure 7. The analysis brought conclusions gathered in the following section.

5. Conclusions

Analysis of each wheel separately was necessary to study the behavior of each wheel under the different possible mass distribution. Situation, when the mass is located in center of gravity of platform is most convenient, because parameters for all wheels are likewise. The most undesirable, but still possible configuration is, when the platform is subjected to load in any positions. On the basis of the obtained results can be stated that when the platform is subjected to load in any position the most exposed is wheel the closest to the load. This can determine the unexpected behavior of the whole system.

The model, built on the basis of the platform kinematics description, allows the analysis of the answers to the control system action, with the possibility of a determination of the movement parameters for both platform and its components.

The previous studies on the kinematics confirmed the correctness of the analysis for proposed solution of prototype of the mobile platform. The proposed design concept is intended to facilitate further research, both experimental and theoretical, the dynamic effects, which may occur during the movement of objects, in particular in the case of maximizing the motion velocities and to analyze the platform motion during the change of the motion direction.

This work assumption was that the platform motion takes place under the conditions without slippage. Presented in the paper the mileages of changes the friction forces can cause slippage with respect to the wheels, where the determined values of friction forces reach its limit values (exceed the developed friction). Such cases will be subject of further research.

References

[1] M. R. Azizi, D. Naderi, Dynamic modeling and trajectory planning for a mobile spherical robot with a 3Dof inner mechanizm, Mechanism and Machine Theory 64 (2013) 251-261.

[2] G. Campion, G. Bastin, B. D'Andréa-Novel, Structural Properties and Classification of Kinematic and Dynamic Models of Wheeled Mobile Robots, IEEETransactions on robotics and automation, 12, 1 (1996) 47-62.

[3] L. Caracciolo, A. Luca De, S. Iannitti, Trajectory Tracking Control of a Four-Wheel Differentially Driven Mobile Robot, IEEE International Conference on Robotics & Autoamtion Detroit, 1999, pp. 2632-2638.

[4] R. Carelli, G. Forte, L. Canali, V. Mut, G. Araguas, E. Destefanis, Autonomous and teleoperation control of a mobile robot, Mechatronics, 18 (2008) 187-194.

[5] K.D. Do, Output-feedback formation tracking control of unicycle-type mobile robots with limited sensing ranges. Robotics and Autonomous Systems, 57 (2009) 34-47.

[6] H.-C. Huang, C.-C. Tsai, Adaptive Robust Control of an Omnidirectional Mobile Platform for Autonomous Service Robots in Polar Coordinates, Journal of Intelligent and Robotic Systems, 2008, pp. 439-460.

[7] A. Jaskot, B. Posiadała, S. Śpiewak, Dynamics Model of the Four-Wheeled Mobile Platform, Dynamical Systems, Mechatronics and Life Sciences, Lodz University of Technology, 2015, pp. 227-236.

[8] A. Jaskot, B. Posiadała, S. Śpiewak, Dynamics Model of the Three-Wheeled Mobile Platform, 22ndInternational Conference Engineering Mechanics 2016, Svratka, Czech Republic, 2016, pp. 250-253.

[9] A.P. Khoukhi, Data-driven multi-stage multi-objective motion planning of mobile robots, application to near minimum power fuzzy parking. Computers and Electrical Engineering, 43 (2015) 218-237.

[10] K. Kozłowski, D. Pażdzierski, Modeling and control of a wheel skid-steerring mobile robot. International Journal of Applied Mathematics and Computer Science,14, 4 (2004) 477-496.

[11] N. Sidek, N. Sarkar, Dynamic Modeling and Control of Nonholonomic Wheeled Mobile Robot when subjected to wheel slip, VDM Verlag Dr. Müller Aktiengesellschaft & Co. KG, Saarbrücken, 2009.

[12] M. Stania, B. Posiadała, Kinematyka prototypowej konstrukcji pojazdu autonomicznego, Mechanik, 12, 2011 (in Polish).

[13] I. Zohar, A. Ailon, R. Rabinovici, Mobile robot characterized by dynamic and kinematic equations and actuator dynamics: Trajectory tracking and related application, Robotics and Autonomous Systems, 59 (2014) 343-353.