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Kinematics of a Robot with Crawler Drive

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In this article authors presenting problems connected with the kinematics modeling mobile robot with crawler drive. This robot has been designed to enable monitoring and analysis of the technical state of pipes and water tanks. Simulations of the kinematics parameters have been made and the results are shown.

Keywords: Kinematics, modelling, mobile robot, crawler module

1. Introduction

In order to describe the kinematics of the robot with crawler drive it is necessary to present kinematics equations. The problem of mathematical description of the kinematics equations of consideration to tracked skidding drive has been presented. In the Matlab^{TM}–Simulink environment simulation of the robot's kinematics behaviour has been carried out. Such a mode of computations software have been further discussed in paper [1,7,8]. On the basis of kinematics parameters simulation and comparison of the results have been carried out.

2. Kinematics description of the robot

On the crawler module track drive different types of variables interact over time. Description of crawler motion in real conditions, with the uneven ground with variable parameters, it is very complicated and therefore it is necessary to use simplified models [5, 6, 7, 8]. In addition to the widely-used crawler made ??up of cells, there are also crawlers made up of an elastomeric belt. They constitute one element with the clutches (Fig. 1a). The propulsion system of the analyzed robot, the two modules connected to the frame (Fig. 1b, Fig. 2).

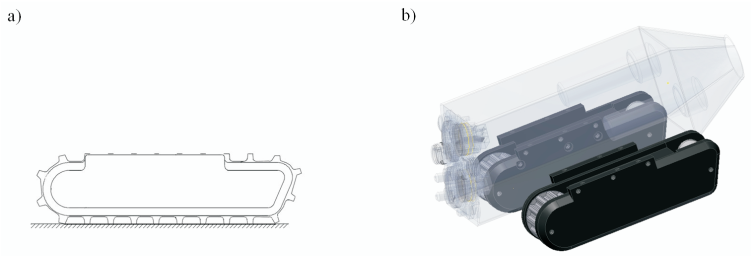

Figure 1 a) Drive module, b) CAD model

Components modules (Fig.2):

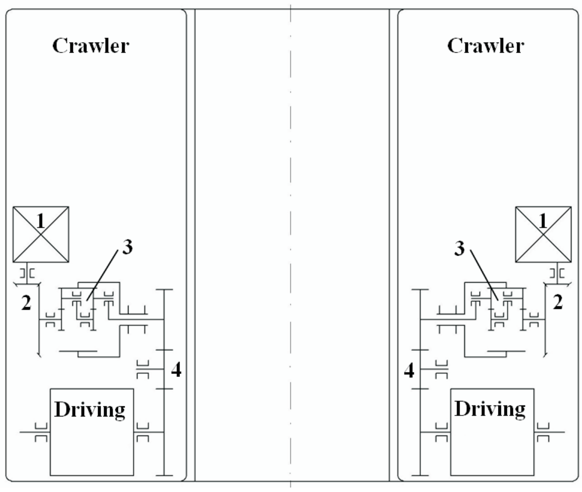

Figure 2 Transmission: 1 – motor, 2 – bevel gear, 3 – planetary gear, 4 – reduction gear

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Individual gear ratios are:

$i_1 = 25 : 8$ – bevel gear,

$i_2 = 16 : 1$ –planetary gear,

$i_3 = 10 : 7$ – reduction gear.

The total gear ratio drive module are:

$$i = 500 : 7$$

On the basis of the previous assumptions the robot moves on caterpillars. The movement of the any point of the caterpillars is connected with composition of two motions (Fig. 3)

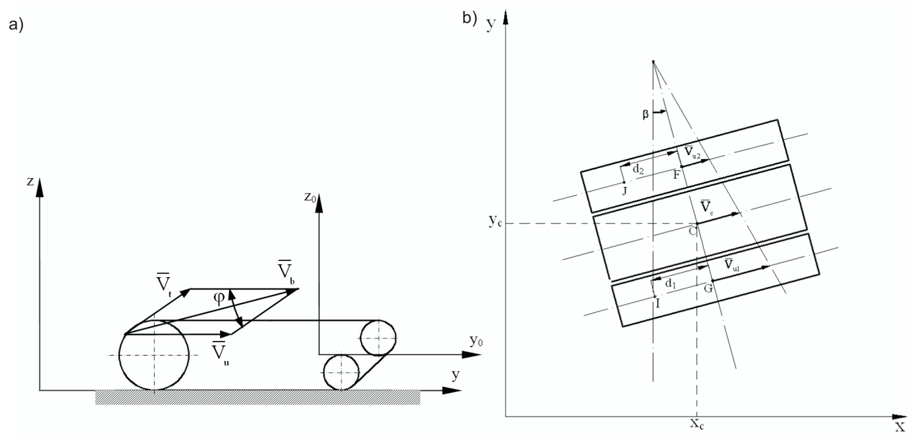

Figure 3 a) The simplified caterpillar model, b) The frame rotation scheme

The first motion is connected with relative motion according to the y_0, $z_0$system of coordinates, while the second is connected with the drift motion relative to the stationary y, z system of coordinates. The absolute velocity of any point on the track perimeter is equal to the geometric velocity of the drift and relative velocity (11, 12, 13).

$$V_{by}= V_u+V_t cos\varphi \tag{1}$$

$$V_{bz}= V_t\ sin\varphi \tag{2}$$

$$V_b=\sqrt{V_{by}^2+V_{bz}^2}=\sqrt{V_u^2+V_t^2+2V_uV_t cos\varphi} \tag{3}$$

where:

V_u – drify velocity;

V_t – relative velocity of the any point on the on the track perimeter;

V_b – absolute velocity of the point on the track perimeter;

φ – the angle between the velocities V_t and V_u.

When there is movement of the carrier section of the track relative to the ground slip phenomenon occurs. Slip Track influenced mainly by the following factors: ground properties, occurring driving force, type and deployment of the clutches of the track.

Existing in the caterpillar system, the driving force causes the shear forces on the ground. Relationship between the common factors can be determined by the equation [2, 3, 4]:

$$P_n = 10^6 b \int_0^L \tau_x dx \tag{4}$$

where:

P_n – driving force;

b – track width;

L – track carrier segment length;
τ_x – shear stress in the soft ground.
The maximum shear stress in the soft ground defines a Coulomb model [2, 3, 4]:

$$\tau_{\max} = c + \mu_0 \sigma = c + \sigma tg\rho \tag{5}$$

where:
ρ – internal friction angle of the ground particles
σ – compressive stresses in the ground
μ_0 – friction coefficient between the ground particles together
c – density of the ground.

The formula for the shear stress depends on the deformation, based on the mathematical analogy between the course of the curves of shear stress and the course of the damped oscillation amplitude of the curve gave Bekker, they have the form(12, 13):

$$\tau_x = (c + \sigma tg\rho) \frac{e^{(-K_2+\sqrt{K_2^2-1})K_1 \Delta l_x} - e^{(-K_2-\sqrt{K_2^2-1})K_1 \Delta l_x}}{Y_{\max}} \; [MPa] \tag{6}$$

where:
Y_{max} – The maximum value of the expression given in the numerator fraction
Δl_x – deformation of the ground layer at x, caused by slipping, parallel to the ground
K_1 – coefficient of the ground deformation during the shearing
K_2 – coefficient characterizing the curve $\tau = f(s)$.

Assuming that, in the course of deformation parallel to the ground is linear, these deformation can be expressed by the formula:

$$\Delta l_x = x s_b \tag{7}$$

where:
s_b – slip calculated from formulas (5) and (7);
x – distance from the point for which the slip is calculated to the point of contact with the ground of track, the largest slip occurs for $x = L$.

On the bases of the description connected with the contact of the track with the ground it is possible to describe the rotation of our robot in the x,y system of coordinates, it is necessary to assume the characteristic point of the robot C. The scheme of robot motion has been presented in Fig.4. The velocity components of point C can be written as, after extension by angular velocity of the frame we receive kinematics equations in the form with allow to solve forward kinematics problem:

$$\dot{x}_C = \frac{r\dot{\alpha}_1(1-s_1) + r\dot{\alpha}_2(1-s_2)}{2} \cos\beta \tag{8}$$

$$\dot{y}_C = \frac{r\dot{\alpha}_1(1-s_1) + r\dot{\alpha}_2(1-s_2)}{2} \sin\beta \tag{9}$$

$$\dot{\beta} = \frac{r\dot{\alpha}_2(1-s_2) - r\dot{\alpha}_1(1-s_1)}{H} \tag{10}$$

In order to achieve the desired trajectory it is necessary to solve the inverse kinematics problem, on the basis of dependence (8) and (9) the for of the inverse kinematics equations have been presented in the following form, where H is a distance between the axes of the tracks (12, 13):

$$V_C = \sqrt{\dot{x}_C^2 + \dot{y}_C^2} \tag{11}$$

$$\dot{\alpha}_1 = \frac{V_C - 0,5\dot{\beta}H}{r(1-s_1)} = \frac{500(V_C - 0,5\dot{\beta}H)}{7r\left(1 - \frac{(n-1)\Delta l'}{L}\right)} \tag{12}$$

$$\dot{\alpha}_2 = \frac{V_C + 0,5\dot{\beta}H}{r(1-s_1)} = \frac{500(V_C + 0,5\dot{\beta}H)}{7r\left(1 - \frac{(n-1)\Delta l'}{L}\right)} \tag{13}$$

Taking into account the gear ratio

$$\dot{\alpha}_{1s} = \frac{500\left(V_C - 0,5\dot{\beta}H\right)}{7r\,(1-s_1)} \tag{14}$$

$$\dot{\alpha}_{2s} = \frac{500\left(V_C + 0,5\dot{\beta}H\right)}{7r\,(1-s_2)} \tag{15}$$

obtained depending on the angular velocity driving motors. This kinematic equations allow to control the position and orientation of the robot and to trace desired trajectory.

3. Simulation

With the use of kinematics and dynamics description of the robot the simulations have been carried out in order to fit construction parameters to optimal work conditions by the robot. In many cases the work environment of the inspection robot is not limited to horizontal surfaces. Sometimes the robot has to overcome the height difference and, therefore, to obtain a more comprehensive analysis of the robot's movement must also be performed in case of motion on the hill.

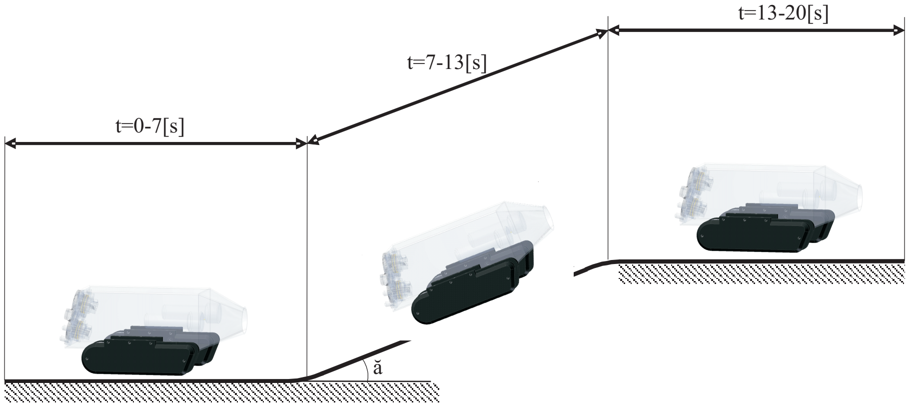

Figure 4 The straight trajectory assumed for the simulation

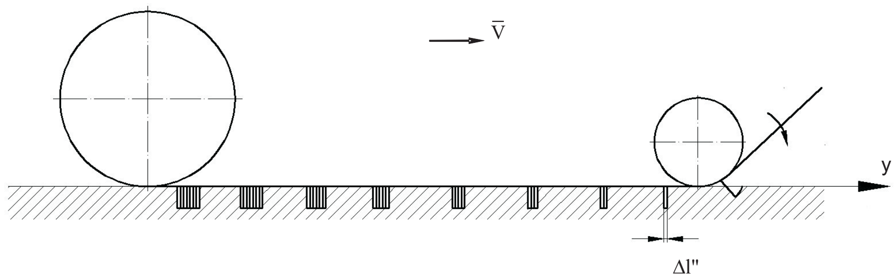

Figure 5 Deformation of the clutch

In the analyzed case the robot moves (Fig. 5) on the ground with a slope $\gamma = 20^o$ and $V_C = 0,15$ [m/s], where the track carrier segment length is equal $L = 0,127$ [m], the quantity of clutches on truck equals $n = 8$, $\Delta l^{'} = 0,002$ [m] the deformation of the clutch (Fig. 6), the radius of the driving wheel of truck $r = 0,02794$ [m] and the distance $H = 0,145$ [m]. After assumption of the velocity of characteristic point

C (Fig. 7) we are receive the kinematic parameters as follows:

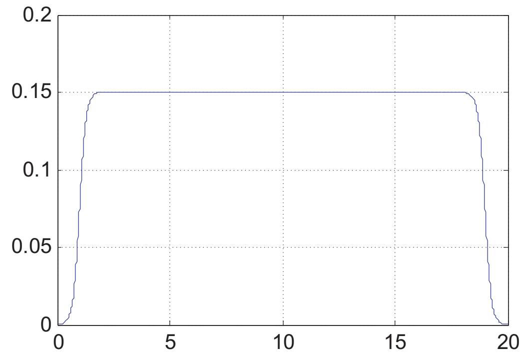

Figure 6 Calculated velocity of the point C

Graphs without skid $\Delta l^{'} = 0[\mathrm{m}]$.

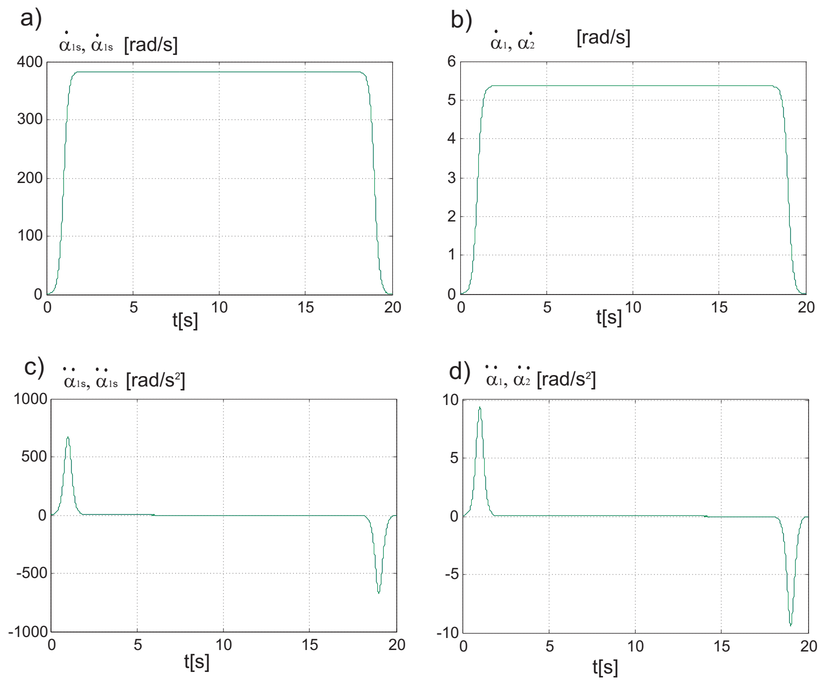

Figure 7 a) Angular velocities of motor shafts, b) Angular velocities the driving wheel caterpillars, c) Angular acceleration of the motor shafts, d) Angular acceleration of the driving wheel caterpillars

Graphs of skid $\Delta l^{'} = 0{,}002[\mathrm{m}]$.

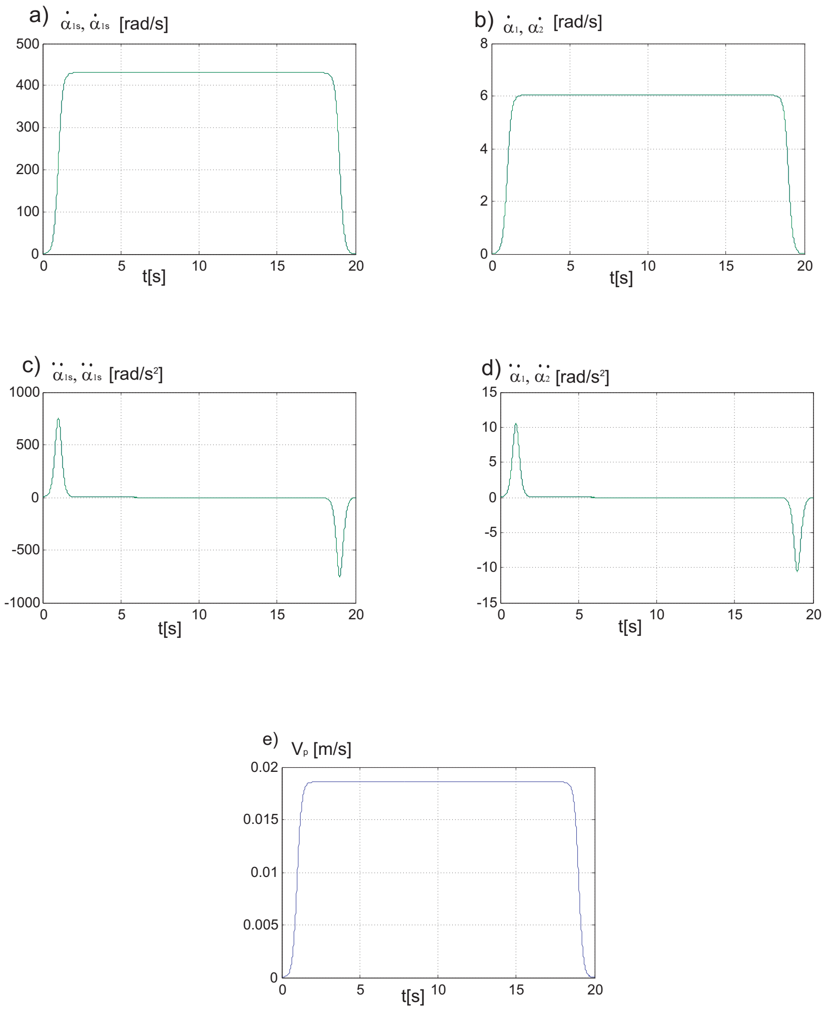

Figure 8 a) Angular velocities of motor shafts, b) Angular velocities the driving wheel caterpillars, c) Angular acceleration of the motor shafts, d) Angular acceleration of the driving wheel caterpillars, e) The skid velocity

As can be observed, for the kinematics simulation, taking into account single horizontal ground deformation, slip velocity appear (Fig. 8.e). Increases the kinematic parameters (comparing Fig.7.a, b, c, d and Fig. 8.abcd) at the same velocity (Fig. 6). However, this parameters increase is in fact limited by the driving system (speed, power the drive motor), which leads to the fact that the robot starts moving with lower speed ever lost to the slip velocity. Those parameters we can use in dynamics and control modeling.

4. Summary

The analysis of the kinematics and motion simulation takes into account factors slipping track–dependent deformation of the substrate and claws. This approach will be used for more detailed analysis taking into account additionally the turning of the robot on the hill. This will also be necessary during the identification and control this type of object.

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