Dynamic analysis of a Triglide parallel robot

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Abstract. **This paper presents the analytical dynamic modeling of a Triglide parallel robot and numerical simulation using Maple and Adams software. The Lagrange with multipliers method was successfully applied to develop the closed-form dynamic model using the Maple software. Next, an equivalent dynamic virtual model of the Triglide parallel robot was developed and simulated in ADAMS program on different task. The simulation of the theoretical dynamic models (closed-form model) and ADAMS numerical approach confirm the validity of the analytical dynamic model.**

Keywords**: Parallel robot, dynamic model, Triglide structure.**

I. INTRODUCTION

THE parallel robots have begun to make the object of study in priority at the last three decades. In this period, important contributions were done specially on the parallel robot modelling: kinematics [1] and dynamics [2].

Because the parallel robots are closed kinematics chains, constituted by a mobile platform with n degree of freedom, connected to the fixed base by serial or complex kinematics chains, the dynamic modelling proves to be complex even in the rigid body hypothesis.

Regarding the dynamic modelling of the parallel robots, different methods can be applied. A method using the Lagrange – D'Alembert formulation has been applied by Yen and Lai [3] for obtaining the dynamic equations of a 3-DOF translational parallel robot.

The virtual work principle was usefully applied by Wu et al. [4] for obtaining the dynamic equation for a 3DOF parallel robot and the obtained driving forces were optimized by applying the least-square method.

Li and Xu [5] derived the analytical dynamic model of a translational parallel robot using the dynamic equations obtained via the virtual work principle and validated on a virtual prototype with the ADAMS software.

In this paper, a kinematical and dynamical modeling for the Triglide parallel robot is presented.

A kinematical analyzes and simulation of Triglide parallel robot has done by Arochia Aelvakumar et al [6].

A kinematical model of the TRIGLIDE parallel robot is presented in [7-8].

The Lagrange method with multipliers was used to derive the closed form dynamic model in the rigid links hypothesis. Based on numerical examples, the dynamic closed form models were validated through MBS prototyping in ADAMS environments.

II. KINEMATICS OF THE CONSIDERED TRIGLIDE PARALLEL ROBOT

The considered Triglide parallel robot (Figure 1) has 3 degrees of freedom (DOF) and is derived of Delta parallel robot. This parallel robot has three legs of type parallelogram (Figure 1), connected to the mobile platform by spherical joints and to the fixed base by linear motors (translational joints – q_1, q_2 and q_3). Each leg has 4 spherical joints and one driving translational joint.

Typically, the study of the robot kinematics is divided into two parts: inverse kinematics and forward (or direct) kinematics. The inverse kinematics problem involves a known pose (position and orientation)/ velocity/ acceleration of the moving platform to obtain the active joint movement (joint displacements/ velocities/ acceleration) that will achieve that imposed end-effector movements.

The forward kinematics problem involves the mapping from a known set of input joint variables/ velocities/ accelerations to a pose of the moving platform that results from those given input displacement/velocity/acceleration. However, the inverse and forward kinematics problems of the former parallel robots can be described in closed form. The direct kinematical model describes the moving platform absolute velocity (v_{xp}, v_{yp}, v_{zp}) in relation with driving velocities ($\dot{q}_1, \dot{q}_2, \dot{q}_3$):

$$\begin{bmatrix} v_{xp} \\ v_{yp} \\ v_{zp} \end{bmatrix} = J_p \cdot \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix}, \tag{1}$$

where Jp is the robot Jacobian analytically established.

The inverse geometrical modeling of the considered Triglide parallel robot permits to obtain the liaison between independent joint variables {q_1, q_2, q_3} and the moving platform coordinates {x_p, y_p, z_p}:

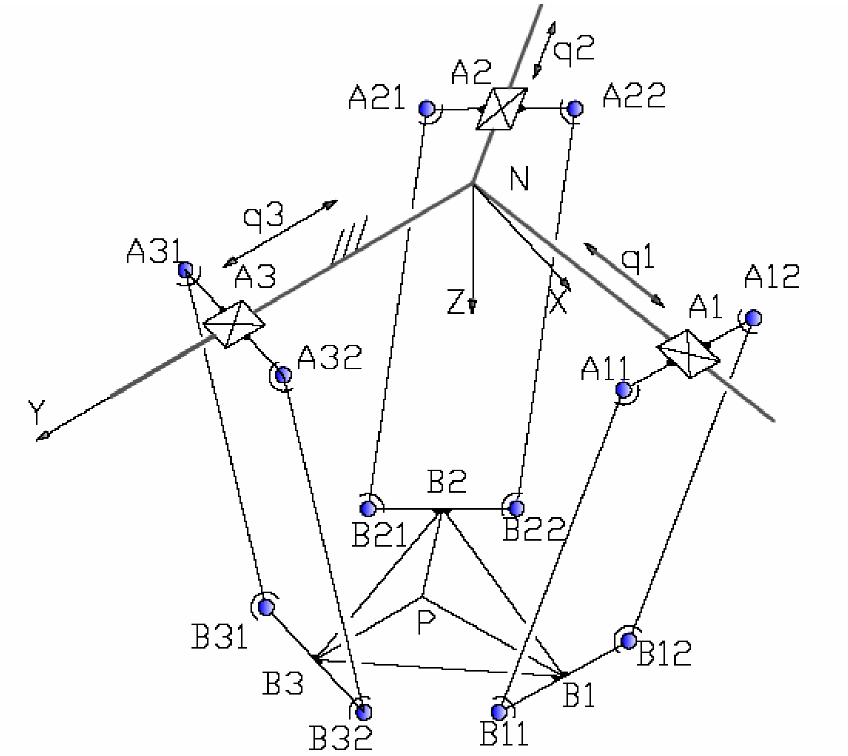


Fig. 1. The kinematical structure of the considered Triglide parallel robot

$$\begin{cases} q_1 = -\frac{1}{2} y_p + x_p \sqrt{3} - L_4 + L_3 + \\ \frac{1}{2}\sqrt{-3{y_p}^2 - 2 y_p x_p \sqrt{3} - {x_p}^2 + 4{L_2}^2 - 4{z_p}^2} \\ \\ q_2 = -\frac{1}{2} x_p \sqrt{3} - L_4 - \frac{1}{2} y_p + L_3 + \\ \frac{1}{2}\sqrt{-{x_p}^2 + 2 y_p x_p \sqrt{3} - 3{y_p}^2 - 4{z_p}^2 + 4{L_2}^2} \\ \\ q_3 = y_p - L_4 + L_3 + \sqrt{{L_2}^2 - {x_p}^2 - {z_p}^2} \end{cases}, \tag{2}$$

where: $L_1=A_{i1}A_{i2}$; $L_2=A_{i1}B_{i1}$; $L_3= NB_i$; $L_4+q_i=NA_i$; with i=1, 2, 3.

Deriving the relation 2, the inverse kinematical model is obtained:

$$\begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = {J_p}^{-1} \cdot \begin{bmatrix} v_{xp} \\ v_{yp} \\ v_{zp} \end{bmatrix}, \tag{3}$$

where:

$${J_p}^{-1} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}, \tag{4}$$

with:

$$a_{11} = \frac{1}{2}\sqrt{3} + \frac{1}{4}\frac{-2 y_p \sqrt{3} - 2 x_p}{\sqrt{-3{y_p}^2 - 2 y_p x_p \sqrt{3} - {x_p}^2 + 4{L_2}^2 - 4{z_p}^2}}$$

$$a_{12} = -\frac{1}{2} + \frac{1}{4}\frac{-6 y_p \sqrt{3} - 2 x_p \sqrt{3}}{\sqrt{-3{y_p}^2 - 2 y_p x_p \sqrt{3} - {x_p}^2 + 4{L_2}^2 - 4{z_p}^2}}$$

$$a_{13} = -2\frac{z_p}{\sqrt{-3{y_p}^2 - 2 y_p x_p \sqrt{3} - {x_p}^2 + 4{L_2}^2 - 4{z_p}^2}}$$

$$a_{21} = -\frac{1}{2}\sqrt{3} + \frac{1}{4}\frac{2 y_p \sqrt{3} - 2 x_p}{\sqrt{-{x_p}^2 + 2 y_p x_p \sqrt{3} - 3{y_p}^2 + 4{L_2}^2 - 4{z_p}^2}}$$

$$a_{22} = -\frac{1}{2} + \frac{1}{4}\frac{2 x_p \sqrt{3} - 6 y_p}{\sqrt{-{x_p}^2 + 2 y_p x_p \sqrt{3} - 3{y_p}^2 + 4{L_2}^2 - 4{z_p}^2}}$$

$$a_{23} = -2\frac{z_p}{\sqrt{-{x_p}^2 + 2 y_p x_p \sqrt{3} - 3{y_p}^2 + 4{L_2}^2 - 4{z_p}^2}}$$

$$a_{31} = -\frac{x_p}{\sqrt{-{x_p}^2 + {L_2}^2 - {z_p}^2}}$$

$$a_{32} = 1$$

$$a_{33} = -\frac{z_p}{\sqrt{-{x_p}^2 + {L_2}^2 - {z_p}^2}}$$

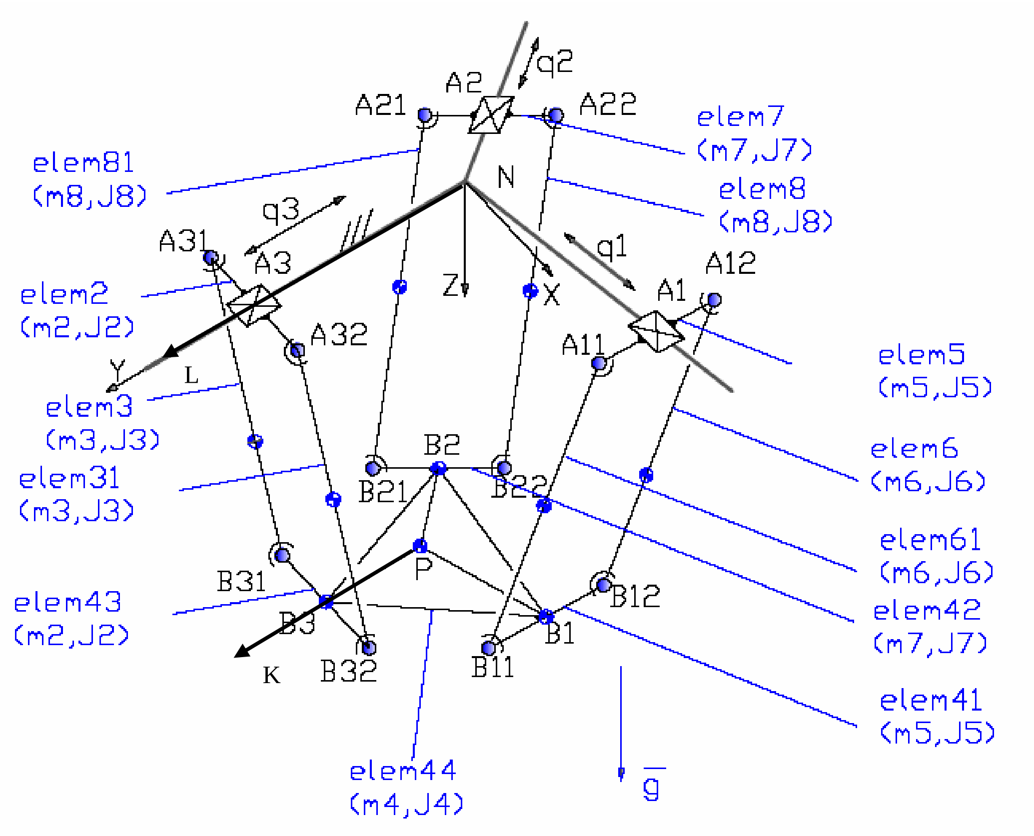


Fig. 2. The dynamical diagram of the Triglide parallel robot

III. DYNAMICAL MODELING OF TRIGLIDE PARALLEL ROBOT

The dynamic modeling has been done in the following prerequisites:
a) The elements are rigid bodies;
b) The gravity vector is oriented in negative sense of the z axis (Figure 2);
c) No external load on the moving platform;
d) The inertial matrix $J_3=J_6=J_8$ and $J_2=J_5=J_{7;}$
e) The mobile platform (the element no. 4) contains four parts (sub-elements): 41, 42, 43 and 44.

Considering rigid elements with distributed masses, the dynamic model can be analytically developed using the Lagrange multipliers method:

$$\sum_{i=1}^{k}\lambda_i \frac{\partial \Gamma_i}{\partial q_j} = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_j}\right) - \frac{\partial L}{\partial q_j} - \hat{Q}_j \quad ,$$

(5) where: λ_i - Lagrange multipliers;

q_j - Displacements from the actuators;

$\hat{Q}_j$ - Generalized external forces;

L - Parallel robot Lagrangean:

$$L = \sum_{i=1}^{n} K_i + \sum_{i=1}^{n} P_i \; , \qquad (6)$$

where: Ki – the kinetic energy of the link i;
Pi – the potential energy of the link i.

The Lagrange multipliers (λ_i) are identified introducing the following set of geometric equations:

- $dist(B_1, B_2) = a$, where a is the side of $\Delta B_1 B_2 B_3$;
- $dist(B_2, B_3) = a$;
- $dist(B_1, B_3) = a$;
- Coordinate after Z of point B1 and B2 need to be the same;
- Coordinate after Z of point B2 and B3 need to be the same;
- Cosine director between L si K (Figure 2) is equal with 1.

Finally, the analytical expression of the driver forces Fq_1, Fq_2 and Fq_3 (see Figure 2) are obtained using Maple software.

Even the obtained analytical dynamic model is complex; this method used can be usefully applied to solve the dynamical model of any 3 DOF parallel robots and can be extended to 4 and more DOF parallel robots.

IV. THE CAD MODEL OF THE TRIGLIDE PARALLEL ROBOT AND SIMULATION RESULTS

The CAD model of the Triglide parallel robot is obtained using ADAMS software and the simple elements of type cylinders (see Figure 3).

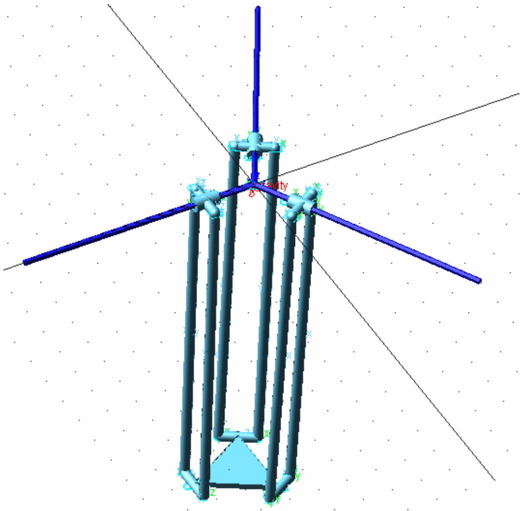


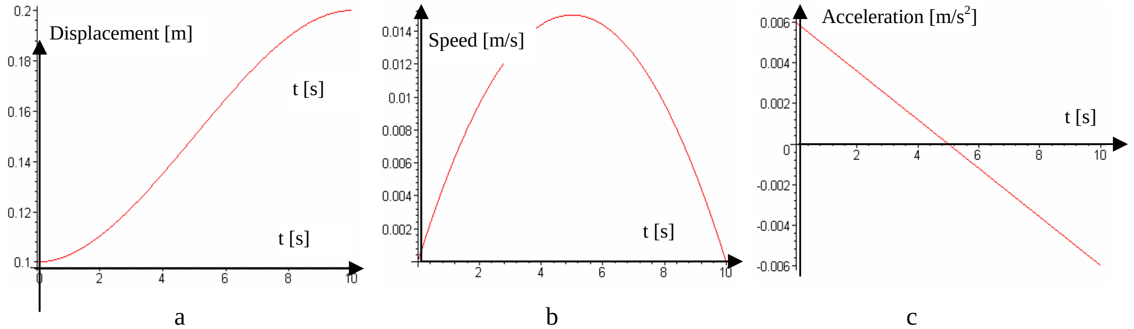
Fig. 3. The CAD model of the Triglide parallel robot

The mass and inertial parameters of CAD model obtained (see Table 1) were used also for simulation the analytical model obtained using Maple software.

Numerical simulations of the obtained models are carried out considering a linear trajectory in the operational space, using a three degree polynomial low of movement of motor B3 (see Figure 1) with 0.1m in 10s (presented in Figure 4).

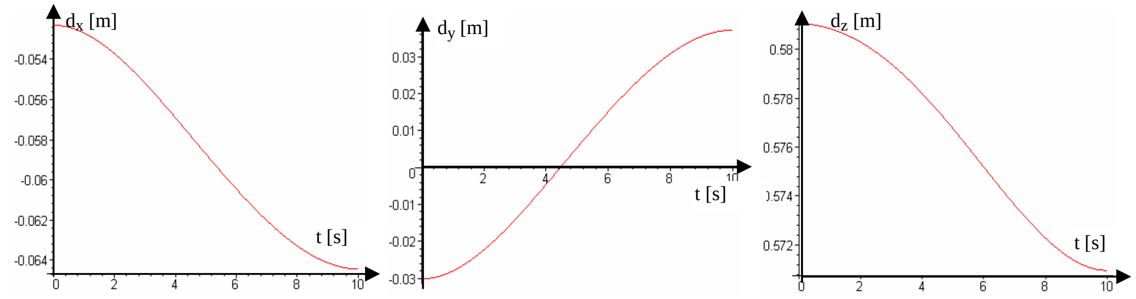
	M	Ixx	Iyy	Izz	Ixy, Iyz, Izx
	[kg]	[kg*m^2]			
Element 3, 6, 8	0.941	2.824 $*10^{-2}$	2.824 $*10^{-2}$	3.011 $*10^{-5}$	0
Element 4	0.570	8.015 $*10^{-4}$	4.055 $*10^{-4}$	4.055 $*10^{-4}$	0

Table 1: The elements' inertial property of the considered Triglide parallel robot



a b c

Fig. 4. The q_3 movement (a-displacement; b-speed, c-acceleration) of the Triglide parallel robot



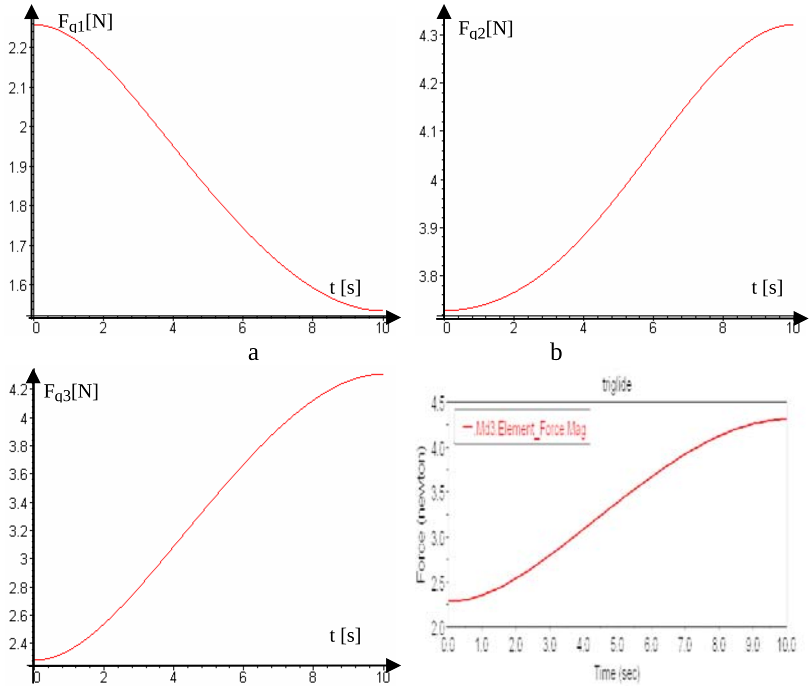
a b c

Fig. 5. The displacement of the mobile platform (of the Triglide parallel robot) after X (a), Y (b) and Z (c) axis

In this way, for the movement in active joint q_3 of 0.1m we obtain a maximal speed major then 0.014m/s and an acceleration major then 0.006m/s^2 (Figure 4).

The displacements of the mobile platform (Figure 5) have the same rate of curve with displacement of motor q_3, obtaining a displacement of 0.012m after X axis, 0.067m after Y axis and 0.01m after Z axis.

The driving force (presented in Figure 6) have the same rate of curve with the displacement impose in active joint q_3, obtaining a maximal value for driving force F_{q2} (4.3N). For verify the correctitude of the analytical model, the same simulation was made in Maple and Adams.



a b

c d

Fig. 6. The driving force of the Triglide parallel robot: F_{q1} (a), F_{q2} (b) and F_{q3} (c) from Maple and F_{q3} (d) from Adams

In Figure 6 is presented for exemplification the result obtained for driving force F_{q3} in the both case (Maple and Adams); the results obtained is the same witch can give the conclusion the analytical model obtained is correct and can be utilized in command and control model of the considered Triglide parallel robot.

V.CONCLUSION

The study highlights the following conclusions:

- The Lagrange with multipliers method for obtaining the dynamic analytical method was successfully applied for this parallel robot using Maple software;
- This numerical simulations effectuated allow to obtain the quantitative dates regarding the kinematical and dynamic response of the parallel robot when the movements from the active joints are known;
- A CAD model was successfully implemented in Adams software to allow to making the numerical simulation in Maple (using the masse and inertial proprieties of the elements of Adams) and also to compare the results obtained for verify the correctitude of the analytical model;
- The results obtained in both models (Maple and Adams) are the same in kinematical and dynamical cases, which go to at the conclusion that the analytical model obtained in Maple is correct;
- In this way, the analytical model obtained can be utilized for obtaining the model of command and control of the considered Triglide parallel robot;
- The presented methodology used for obtaining the analytical dynamic model, with its numerical simulation, can be extended for more type of parallel robot.

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