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COMPUTER GRAPHICS USED TO OVER CONSTRAINED MECHANISMS' MOBILITY

Abstract: *The objective of this study is the use of computer graphics as teaching methodology in the field of robotics, focused on over constrained mechanisms' mobility. Because the analytical methods applied to calculate the mobility of robots have a high mathematical level, but also because certain parameters of over constrained mechanisms are usually determined by structural methods, we have used computer graphics in ADAMS in the teaching process, so that students easily understand the connection between theory and practice, and then solve the engineering applications.*

Key words: *computer graphics, over constrained mechanisms, mobility, teaching methodology.*

1. INTRODUCTION

The computed assisted teaching method is extremely useful in the teaching process, and computer graphics can be successfully applied to optimize mechanical systems, facilitating students' understanding of complex engineering problems.

Researchers implements different methods in programming languages (such as Mathlab, Mathcad, Mathematica) or different commercial CAD systems (such as CATIA, ADAMS, ANSYS), in order to optimize some functions in mechanical systems. Sometimes, both, programming language and commercial programs are used together for optimization of parameters of mechanical systems, as robots [9].

If ADAMS software is used to optimize mobile mechanical systems, it is necessary to introduce the known movements in driving joints, this means that is necessary to know the mobility of system. Applying analytical methods to determine the mobility always ensures correct results, but for some mechanisms the calculus of the velocity system rank is difficult. Also, the general structural formula (Eq. 1), which is used to determine the mobility in overconstrained mechanisms, may raise some difficulty in settings its terms, as it requires a visual inspection of the movements of spatial chain elements.

$$M = \sum_{i=1}^{p} f_i - \sum_{j=1}^{q} b_j - \sum_{k=1}^{p} f_{passivek} . \qquad (1)$$

where:
q = the number of independent chains,
p = the number of joints of mechanism,
f_i = the connectivity of joint i,
b_j = the mobility number for the loop j,
$f_{passivek}$ = the number of passive degrees of freedom in the joint k.

Especially for the mobility structural calculus of over constrained mechanisms, theoretically or practical methods there are done by others (such as [1], [2], [3], [4]), but computer graphics can help the process of comprehension of this problem during the teaching process. Many parallel robots have been invented and studied by scientists and their interest is actual due to their high performances, such as accuracy.

In [8] a short state of the art is presented.

In this paper we use the computer graphics with the ADAMS software for some kinematic chains associated with the over constrained mechanisms, and we applied movements in some kinematic joints, to facilitate comprehension and calculation of the terms in the structural formula of over constrained mechanisms' mobility (Eq. 1).

2. PROBLEM DESCRIPTION

2.1 The calculus of mobility

We consider a fully decoupled parallel mechanism, the Tripteron, developed at Laval University, Quebec [5], [6], [7]. The mechanism has a moving platform, that is connected to a base by three legs of identical architecture (Fig.1). Every leg i has one prismatic joint, A_i, and three revolute joints, B_i, C_i, and D_i. The axes of all joints of one leg are parallel.

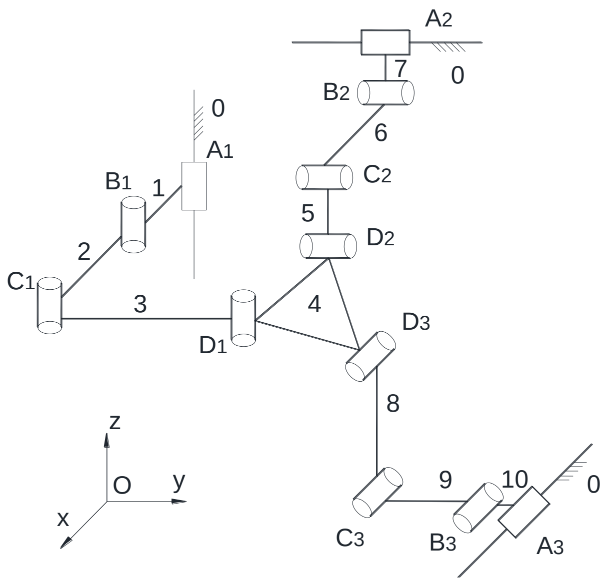

Fig. 1 The kinematic scheme of Tripteron.

To calculate the mobility of parallel platform with Eq. 1, we utilise the concept based on the TRIZ method [1].

In this mechanism there are two independent kinematic loops (q=2):

0-1-2-3-4-5-6-7-0 and *0-1-2-3-4-8-9-10-0*.

We cut twice the base, and we obtain the number of the pairs equal to the number of the kinematic elements, *12*.

Each joint *i* has one degrees of freedom, $f_i = 1$, *i*=1-12. All degrees of freedom of the joints will be calculated with Eq. 2.

$$\sum_{i=1}^{12} f_i = 1+1+1+1+1+1+1+1+1+1+1+1 = 12 \qquad (2)$$

The end-effector connectivity from the first open kinematic chain *0-1-2-3-4-5-6-7-11* (*11* is the segmented base - Fig. 2) associated to the first loop *0-1-2-3-4-5-6-7-0* is *5* $(T_x, T_y, T_z, R_y, R_z)$, that means the first number mobility is *5* ($b_1 = 5$).

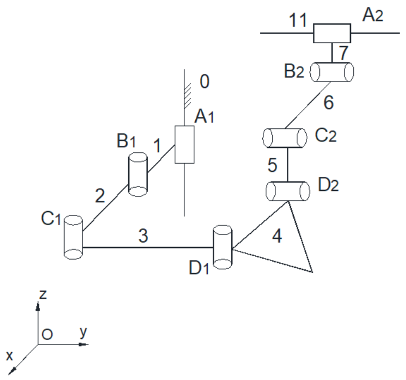

Fig. 2 The first kinematic chain associated to Tripteron.

In the second mechanical system (Fig. 3), composed by the loop *0-1-2-3-4-5-6-7-0* and the kinematic chain *8-9-10-12* (*12* is the segmented base), to analyse the input movements in the kinematic chain *8-9-10-12* is necessary to determine the spatiality of the platform element *4*, from the loop *0-1-2-3-4-5-6-7-0*.

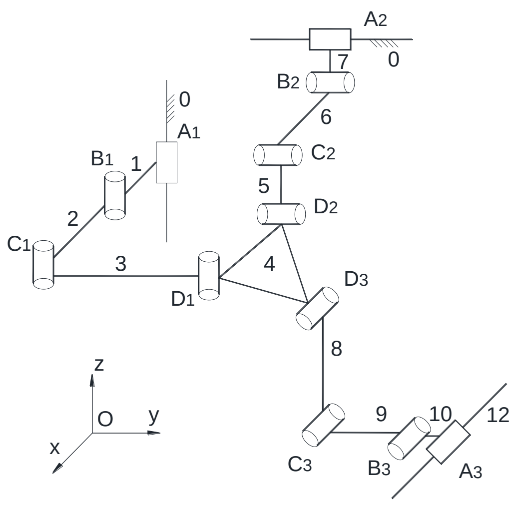

Fig. 3 The second kinematic chain associated to Tripteron.

For that, we intersect the spatiality of the chain *0-1-2-3-4* (T_x, T_y, T_z, R_z) with the spatiality of the chain *0-7-6-5-4* (T_x, T_y, T_z, R_y) - Eq. 3.

$$(T_x, T_y, T_z, R_z) \cap (T_x, T_y, T_z, R_y) = (T_x, T_y, T_z) \quad (3)$$

The spatiality of the extreme element *12* is determined by the spatiality of the platform element *4* and by the relative movements in the chain *8-9-10-12* (Fig. 3).

The mobility number b_2 of the second loop is *4* because the last element, *12*, has *4* degrees of freedom: T_x, T_y, T_z, R_x.

With Eq. 4 we calculate the mobility of Tripteron, and the result is presented in Eq. 5.

$$M = \sum_{i=1}^{12} f_i - \sum_{j=1}^{2} b_j - \sum_{k=1}^{12} f_{passivek} \qquad (4)$$

The number of passive degrees of freedom of the mechanism is zero ($\sum_{k=1}^{12} f_{passivek} = 0$).

$$M = 12 - 5 - 4 - 0 = 3 \qquad (5)$$

We obtain three linear actuators and the mechanism is fully decoupled.

2.2 Computer graphics used in the teaching process

For a better understanding by students of the mobility calculation of over constrained mechanisms using structural formula (Eq. 1), we use computer graphics in the teaching process.

For example, for the Tripteron mechanism, it was modeled with the Solid Works program [11] (Fig. 4), and it was imported into the ADAMS program [10] (Fig. 5).

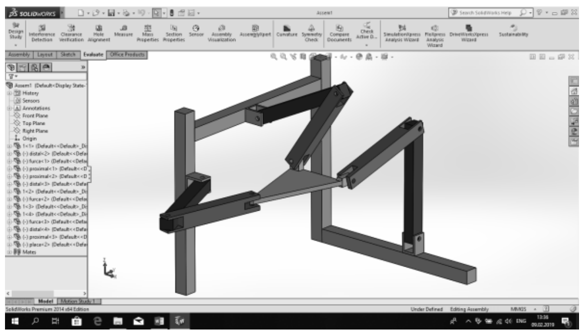

Fig. 4 The Tripteron design with Solid Works.

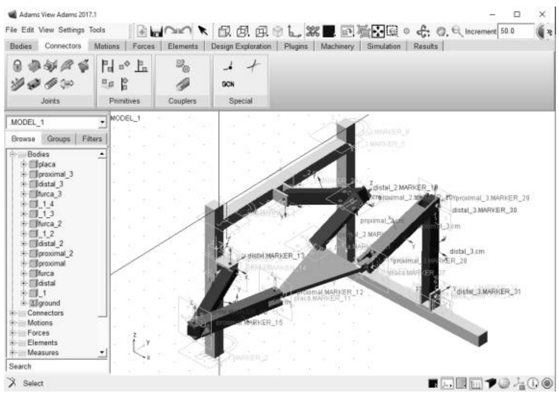

Fig. 5 Tripteron kinematic model with ADAMS/View software

We realised the mechanism motion simulation in ADAMS, to demonstrate students that mechanism successfully functions. Also, it has been verified that it is an over constrained mechanism, that means Grubler-Kutzbach-Cebysev's formula for calculating mobility is not applicable (Fig. 6).

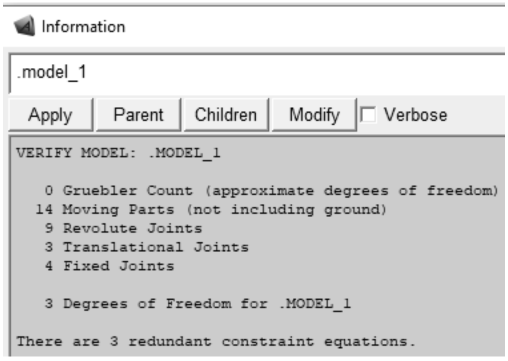

Fig. 6 Tripteron model mobility verify

To demonstrate that connectivity in the first open kinematic chain *0-1-2-3-4-5-6-7-11* (Fig. 2) is 5 ($b_1 = 5$) we modeling in ADAMS this chain with moving end-effector *11* (Fig. 7).

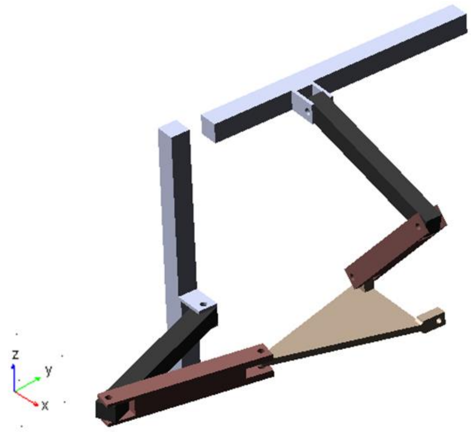

Fig. 7 The first open kinematic chain

First, we define as actuators all eight joints (Fig. 8).

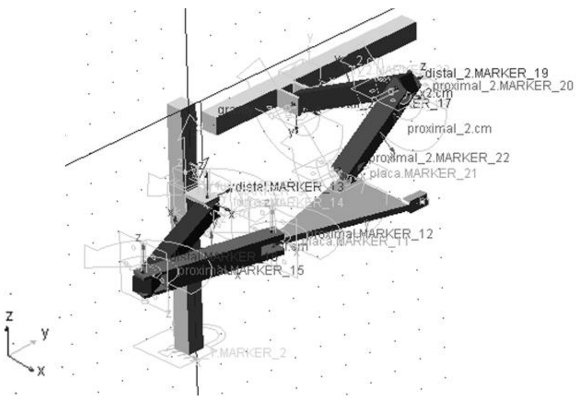

Fig. 8 The first open kinematic chain with eight actuators

The students can observe the spatial motion of the end effector (the element *11* from Fig. 2) during simulation, as a combination of translations and rotations, and the trajectory of the end-effector mass center (Fig. 9, Fig. 10).

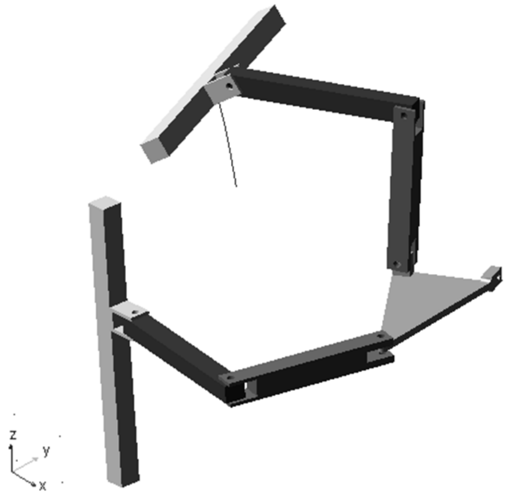

Fig. 9 The first chain with eight actuators during simulation

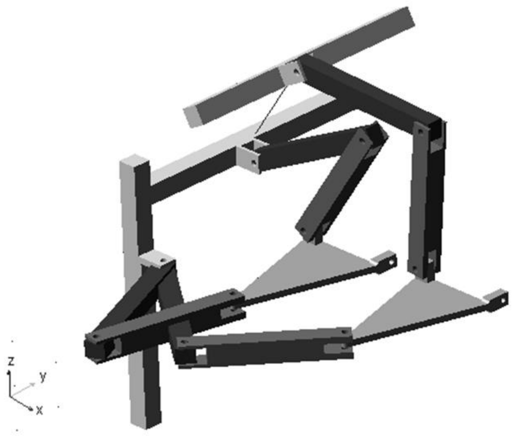

Fig. 10 Two simultaneous positions of the first kinematic chain

From simulation results can be investigated the three translations of the end-effector mass center (Fig. 11) and angular velocities (Fig. 12).

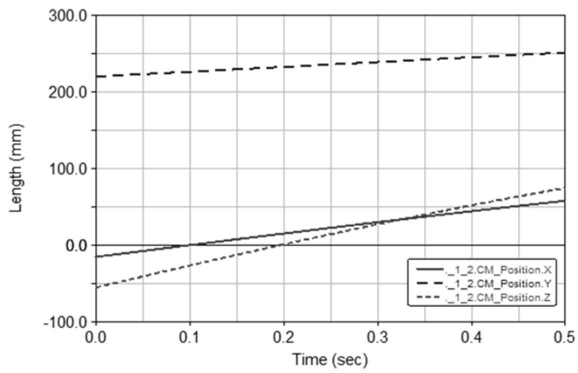

Fig. 11 End-effector translational displacements

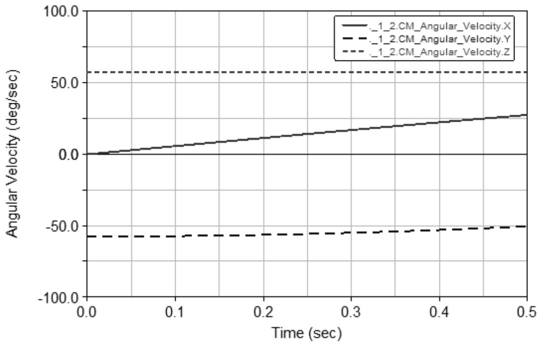

Fig. 12 End-effector angular velocities

To identify each independent motion of the end-effector, we utilise the first open chain (Fig. 2) and successively define driving actuators between ground and end-effector *11* for all six motions, three translations and three rotations along, respectively around axes. For example, in Fig. 13 is presented the image for driving actuator placed between end-effector and ground with rotation around x axis.

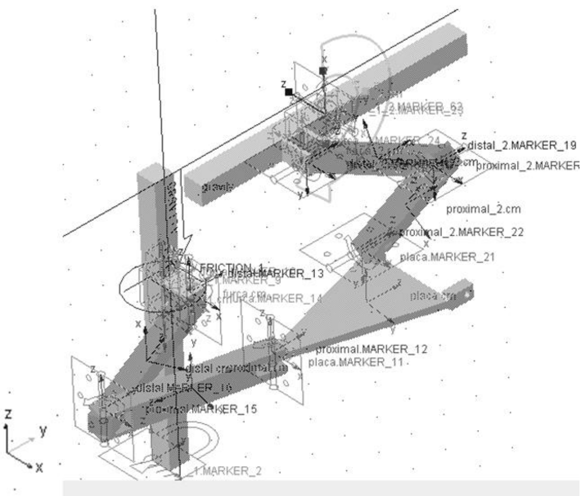

Fig. 13 Define of x axis actuator between ground and end-effector *11* (Fig. 2)

The results of simulations in Fig. 14, Fig. 15, Fig. 16, Fig. 17, Fig. 18 and Fig. 19 are presented.

Fig. 14 End-effector y axis translation

Fig. 15 End-effector x axis translation

Fig. 16 End-effector z axis translation

Fig. 17 End-effector y axis rotation

Fig. 18 End-effector z axis rotation

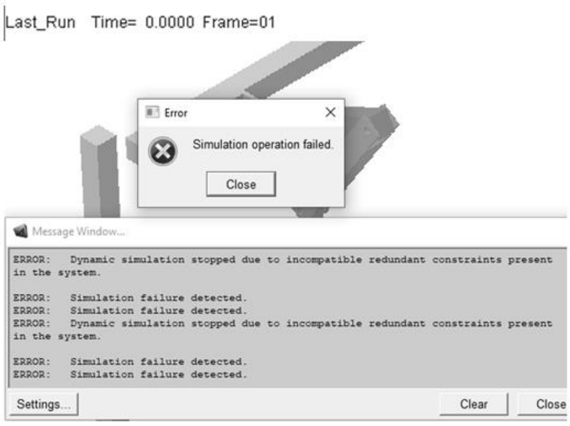

Fig. 19 Failed operation for end-effector x axis rotation

When we define actuator between ground and end-effector with rotation around x axis (Fig. 13), the simulation operation failed (Fig. 19).

Because on can simulate just five motions for the end-effector (one rotation missing – the x axis rotation, Fig. 19), the students will conclude that the mobility number for the first loop is five.

The next step is to design the second chain with the scheme presented in Fig. 3, with the kinematic element *12* as moving part.

We repeat the previous procedure for the second chain, that means successively define driving actuators between ground and end-effector *12*, for all six motions.

When define actuator between ground and end-effector *12*, with rotation around z axis (Fig. 20), the simulation operation failed (Fig. 21).

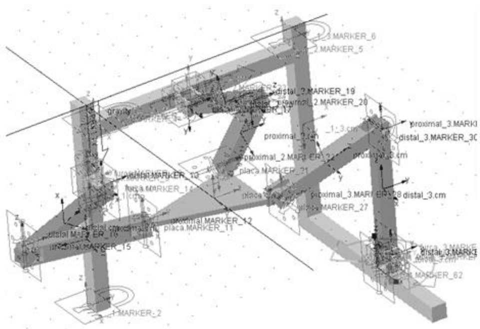

Fig. 20 Define of z axis actuator between ground and end-effector *12* (Fig. 3)

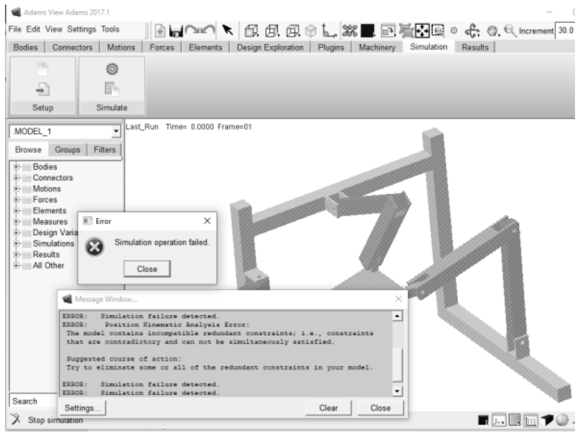

Fig. 21 Failed operation for end-effector z axis rotation

Also, when define actuator between ground and end-effector *12*, with rotation around y axis (Fig. 22), the simulation operation failed (Fig. 23).

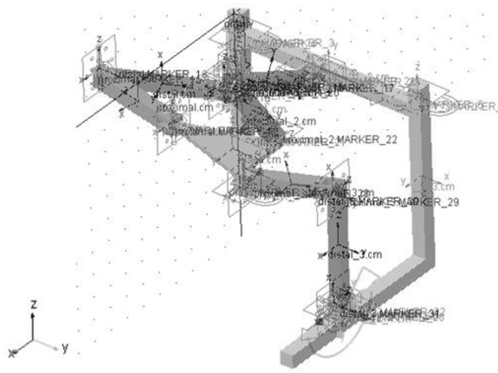

Fig. 22 Define of y axis actuator between ground and end-effector *12* (Fig. 3)

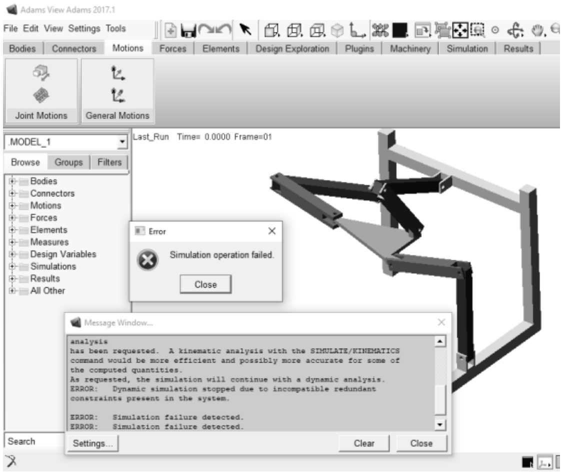

Fig. 23 Failed operation for end-effector y axis rotation

In the second chain on can simulate just four motions for the end-effector *12* (two rotations missing – the y and z axis rotation), that means the mobility number for the second loop is four.

3. CONCLUSION

A new teaching method that use computer graphics and ADAMS software to determine the over constrained mechanisms' mobility with structural formula has been proposed in this paper.

After computer modelling of the parallel robot, the procedure used is very comfortable: we successively split the independent loops and we impose for the end-effector the all six movements (three translations and three rotations along and around the axes of the global referential system) by setting joints between end-effector and ground. The mobility' number for each loop is determined by the number of possible independent movements of the end-effector of the open chain associated to it.

The TRIZ method are the base of the algorithm used in this approach.

The first merit of this teaching method is that students quickly understand the mobility structural formula of overconstrained mechanisms.

The second advantage refers to the fact that is no need to calculate the mobility of parallel platforms after computer modelling of them.

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