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Dynamic Kinematics of the Plan Balanced Chain at the Planar Module 3R

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Abstract: Anthropomorphic robots are, as I have already said, in most of the most widespread and widely used works worldwide today, due to their ability to adapt quickly to forced work, working without breaks or breaks 24 h a day, without unpaid leave without asking for food, water, air, or salary. Anthropomorphic robots are supple, elegant, easy to configure and adapted to almost any required location, being the most flexible, more useful, more penetrating, easy to deploy and maintain. For the first time, these robots have asserted themselves in the automotive industry and especially in the automotive industry, today they have penetrated almost all industrial fields, being easily adaptable, flexible, dynamic, resilient, cheaper than other models, occupying a volume smaller but with a major working space. They can also work in toxic or dangerous environments, so used in dyeing, chemical cleaners, in chemical or nuclear environments, where they handle explosive objects, or in military missions to land or sea mines, even if they were banned to use, because there are still countries around the globe that use them, such as Afghanistan ... In the study of the dynamic movement of robots, i.e their real movement, when considering the actions and effects of the various forces that act upon them, it is important to know the real motion of the robots, ie the dynamic cinematic (the one imposed by the dynamics, that is, the forces in the mechanism).

Keywords: Anthropomorphic Mechatronic Systems, Robots, Total Static Balancing, Kinetostatics, Dynamics, Dynamic Kinematics

Introduction

Anthropomorphic robots are, as I have already said, in most of the most widespread and widely used works worldwide today, due to their ability to adapt quickly to forced work, working without breaks or breaks 24 h a day, without unpaid leave without asking for food, water, air, or salary. Anthropomorphic robots are supple, elegant, easy to configure and adapted to almost any required location, being the most flexible, more useful, more penetrating, easy to deploy and maintain. For the first time, these robots have asserted themselves in the automotive industry and especially in the automotive industry, today they have penetrated almost all industrial fields, being easily adaptable, flexible, dynamic, resilient, cheaper than other models, occupying a volume smaller but with a major working space. They can also work in toxic or dangerous environments, so used in dyeing, chemical cleaners, in chemical or nuclear environments, where they handle explosive objects, or in military missions to land or sea mines, even if they were banned to use, because there are still countries around the globe that use them, such as Afghanistan.

In the study of the dynamic movement of robots, ie their real movement, when considering the actions and effects of the various forces that act upon them, it is important to know the real motion of the robots, ie the dynamic cinematic (the one imposed by the dynamics, that is, the forces in the mechanism).

In some previous papers, the mechatronic module 3R, plan, is a basic module on which the complete, geometric, cinematic, dynamic calculation of the anthropomorphic robots, the most used today's industrial robots, is built. The importance of the study of anthropomorphic robots has also been signaled, being today the most widespread robots worldwide, due to its simple design, construction, implementation, operation and maintenance. In addition, anthromomorphic systems are simpler from a technological and cheaper point of view, performing a continuous, demanding, repetitive work without any major maintenance problems. The basic module of these robots was also presented geometrically, cinematically, of the forces, of its total static balancing and of the forces that arise within or after balancing. In the present paper we want to highlight the dynamics of the already statically balanced total module. It has been presented in other works and studied matrix spatially, or more simply in a plan, but in this case, it is necessary to move from the working plane to the real space, or vice versa, passage that we will present in this study. In the basic plan module already presented in other geometric and cinematic works, we want to highlight some dynamic features such as static balancing, total balancing and determination of the strength of the module after balancing. Through a total static balancing, balancing the gravitational forces and moments generated by the forces of gravity is achieved, balancing the forces of inertia and the moments (couples) generated by the presence of inertial forces (not to be confused with the inertial moments of the mechanism, which appear separately from the other forces, being part of the inertial torsion of a mechanism and depending on both the inertial masses of the mechanism and its angular accelerations. Balancing the mechanism can be done through various methods. Partial balancing is achieved almost in all cases where the actuators (electric drive motors) are fitted with a mechanical reduction, a mechanical transmission, a sprocket, spiral gear, spool screw type. This results in a "forced" drive balancing from the transmission, which makes the operation of the assembly to be correct but rigid and with mechanical shocks. Such balancing is not possible when the actuators directly actuate the elements of the kinematic chain without using mechanical reducers (Antonescu and Petrescu, 1985; 1989; Antonescu *et al*., 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001; Aversa *et al*., 2017a; 2017b; 2017c; 2017d; 2017e; 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; 2016g; 2016h; 2016i; 2016j; 2016k; 2016l; 2016m; 2016n; 2016o; Berto *et al*., 2016a; 2016b; 2016c; 2016d; Cao *et al*., 2013; Dong *et al*., 2013; Comanescu, 2010; Franklin, 1930; He *et al*., 2013; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Mirsayar *et al*., 2017; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu, 2011; 2015a; 2015b; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e; 2011; 2012a; 2012b; 2013a; 2013b; 2016a; 2016b; 2016c; Petrescu *et al*., 2009; 2016; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae).

Figure 1 shows the kinematic diagram of the planar chain and Fig. 2 shows the kinematic scheme of the space chain.

The mechanism in Fig. 1 (planar cinematic chain) must be balanced to have a normal operation.

Through a total static balancing, balancing the gravitational forces and moments generated by the forces of gravity is achieved, balancing the forces of inertia and the moments (couples) generated by the presence of inertial forces (not to be confused with the inertial moments of the mechanism, which appear separately from the other forces, being part of the inertial torsion of a mechanism and depending on both the inertial masses of the mechanism and its angular accelerations.

Balancing the mechanism can be done through various methods. Partial balancing is achieved almost in all cases where the actuators (electric drive motors) are fitted with a mechanical reduction, a mechanical transmission, a sprocket, spiral gear, spool screw type.

Such a reducer called the unisens (the movement allowed by it is a two-way rotation, but the transmission of the force and the motor moment can only be done in one direction, from the spindle to the worm gear, vice versa from the worm gear to the screw the force can not be transmitted and the movement is not possible by blocking the mechanism, which makes it apt to transmit the movement from the wheel of a vehicle to its wheels in the steering mechanism, not allowing the wheel forces due to the unevenness of the ground, to be transmitted to the steering wheel and implicitly to the driver, or this mechanism is suitable for mechanical meters so that they do not twist and vice versa etc.) can balance the transmission by letting the forces and motor moments unfold, but not allowing the kinematic elements to influence the movement through their forces of weight and inertia.

This results in a "forced" drive balancing from the transmission, which makes the operation of the assembly to be correct but rigid and with mechanical shocks.

Such balancing is not possible when the actuators directly actuate the elements of the kinematic chain without using mechanical reducers.

It is necessary in this situation for a real, permanent balancing.

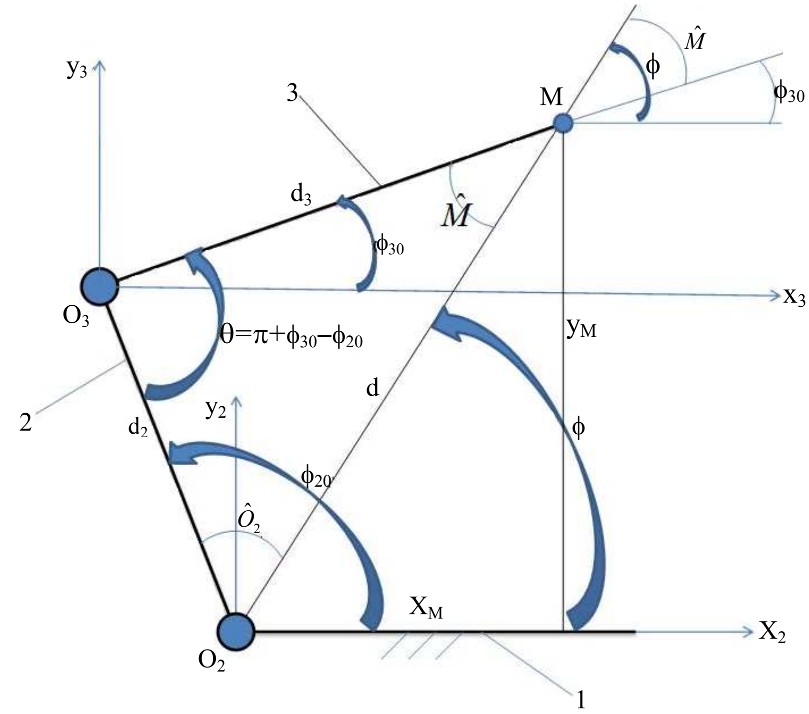

Fig. 1: The kinematic scheme of the plan chain

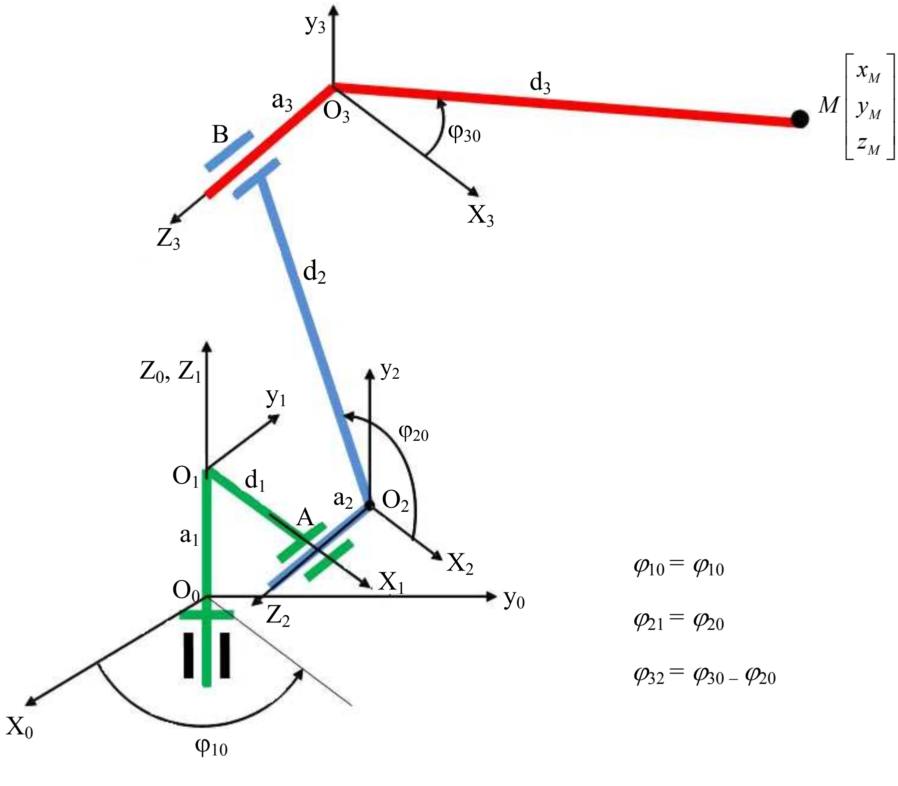

Fig. 2: The kinematic scheme of the spatial chain

In addition, in situations where hypoid reducers are used, it is also good to have a permanent, permanent static balancing that achieves a normal, quiet operation of the mechanism and the whole assembly.

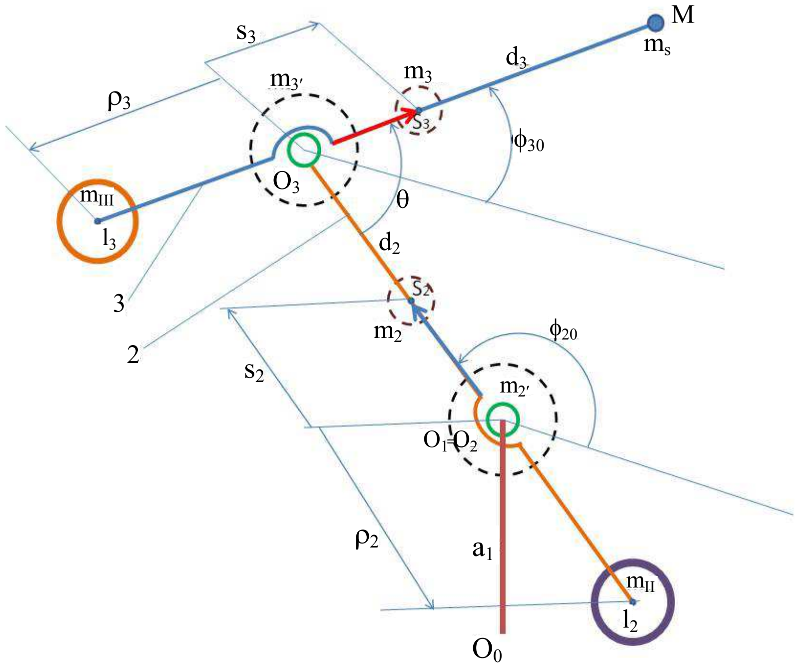

Fig. 3: Balancing the plan cinematic chain

As has already been shown, by balancing the static totality of a mobile cinematic chain, it is possible to balance the weight forces and couples produced by them, as well as balancing the inertial forces and the couples produced by them, but not balancing the moment of inertia.

Arcing balancing methods generally did not work very well, the springs having to be very well calibrated, so that the elastic forces realized (stored) by them are neither too small (insufficient balancing) nor too large (because prematurely kinematic elements and couplers and also greatly forces actuators). The most used method is the classic one, with additional counterweight masses, similar to traditional folk fountains. Total balancing of the open robotic kinematic chain is shown in Fig. 3.

Materials and Methods

The following "scenario" is being pursued. The following parameters are known:

$$x_M, y_M, d_2, d_3, \omega_2, \dot{\theta}, M_{m_2}, M_{m_3}$$

The moments of the electric motors (moments of the actuators) have values that vary in a narrow beach, along with the value of the angular speed of the respective engine, according to the characteristic diagram presented by the respective manufacturer. The variation is generally of the type shown in Fig 4.

As can be seen in Fig 4, the torque variation with the angular velocity is small so that the engine moment can be considered constant over the entire operating portion.

An important observation that should not be overlooked is that both electric, DC and AC motors have a stable operating characteristic.

If the load increases the angular speed of the motor and therefore the mechanism of the (open kinematic chain) decreases by adapting to the increased load and when the load decreases and the operation at a higher natural speed is possible, the angular speed of the actuator increases, according to its internal functional characteristics.

Returning to the dynamic kinematics data, we will continue to pursue computational relationships in a natural order.

It starts with the system (1), which determines the absolute angular velocity of the element 3, that of the element 2 being the same as that of the actuator 2 and for the element 3 the actuator speed 2 must be summed up with that of the motor 3.

Also, in the system (1), the absolute angular accelerations of the two kinematic elements 2 and 3 of the open-chain chain are determined, by means of known relations from the dynamics of the system. System (1) represents the 0 set of relationships in the dynamic kinematics:

$$\begin{cases} \omega_3 = \dot{\theta} + \omega_2 \\ \varepsilon_2 = \dfrac{M_{m_2}}{m_{3'} \cdot d_2^2 + m_2 \cdot s_2^2 + m_{II} \cdot \rho_2^2} = \dfrac{M_{m_2}}{J_{O_2}^*} \\ \varepsilon_3 = \dfrac{M_{m_3}}{m_s \cdot d_3^2 + m_3 \cdot s_3^2 + m_{III} \cdot \rho_3^2} = \dfrac{M_{m_3}}{J_{O_3}} \end{cases} \quad (1)$$

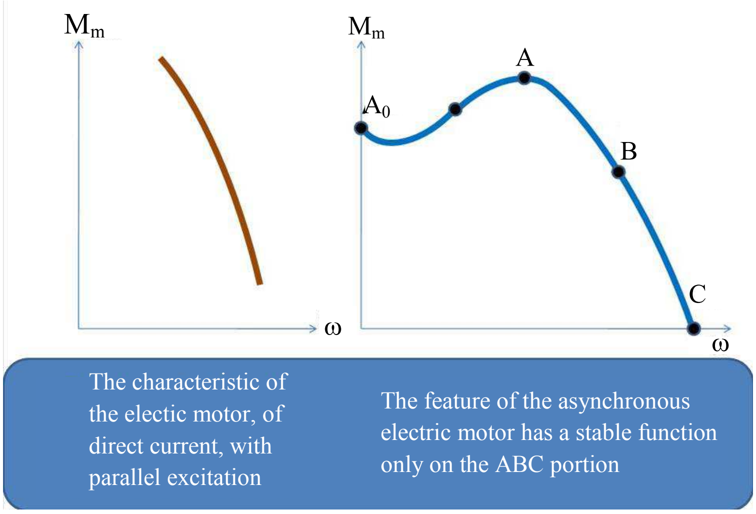

Fig. 4: Characteristics of DC and AC motors (three-phase asynchronous)

Further, the orderly kinematic parameters required with relations (2), considered to be the set I of relations, will be determined in turn:

$$\begin{cases} d=\sqrt{x_M^2+y_M^2} \\ d^2=x_M^2+y_M^2 \\ \cos\phi=\dfrac{x_M}{d} \\ \sin\phi=\dfrac{y_M}{d} \\ \cos O_2=\dfrac{d_2^2+d^2-d_3^2}{2\cdot d_2\cdot d} \\ \sin O_2=\dfrac{\sqrt{4\cdot d_2^2\cdot d^2-\left(d_2^2+d^2-d_3^2\right)^2}}{2\cdot d_2\cdot d} \\ \cos\phi_2=\cos\phi\cdot\cos O_2\mp\sin\phi\cdot\sin O_2 \\ \sin\phi_2=\sin\phi\cdot\cos O_2\pm\sin O_2\cdot\cos\phi \\ x=d_2\cdot\cos\phi_2 \\ y=d_2\cdot\sin\phi_2 \\ \phi_2=semn\left(\sin\phi_2\right)\cdot\arccos\left(\cos\phi_2\right) \\ \cos M=\dfrac{d_3^2+d^2-d_2^2}{2\cdot d_3\cdot d} \\ \sin M=\dfrac{\sqrt{4\cdot d_3^2\cdot d^2-\left(d_3^2+d^2-d_2^2\right)^2}}{2\cdot d_3\cdot d} \\ \cos\phi_3=\cos\phi\cdot\cos M\pm\sin\phi\cdot\sin M \\ \sin\phi_3=\sin\phi\cdot\cos M\mp\sin M\cdot\cos\phi \\ \phi_3=semn\left(\sin\phi_3\right)\cdot\arccos\left(\cos\phi_3\right) \end{cases} \tag{2}$$

Results

Follow the set II of dynamic kinematics relations, the system (3), which generates the linear speeds and accelerations of points O3 and M. For point O3, they will be denoted without a letter as an index and for M will be denoted by M. The set III (4) determines the exact angular velocities and accelerations:

$$\begin{cases} \dot{x}=-y\cdot\omega_2 \\ \dot{y}=x\cdot\omega_2 \\ \ddot{x}=-x\cdot\omega_2^2-y\cdot\varepsilon_2 \\ \ddot{y}=-y\cdot\omega_2^2+x\cdot\varepsilon_2 \\ \dot{x}_M=\dot{x}-\left(y_M-y\right)\cdot\omega_3 \\ \dot{y}_M=\dot{y}+\left(x_M-x\right)\cdot\omega_3 \\ \ddot{x}_M=\ddot{x}-\left(\dot{y}_M-\dot{y}\right)\cdot\omega_3-\left(y_M-y\right)\cdot\varepsilon_3 \\ \ddot{y}_M=\ddot{y}+\left(\dot{x}_M-\dot{x}\right)\cdot\omega_3+\left(x_M-x\right)\cdot\varepsilon_3 \end{cases} \tag{3}$$

$$\begin{cases} \omega_2=\dfrac{\dot{y}\cdot\cos\phi_2-\dot{x}\cdot\sin\phi_2}{d_2} \\ \omega_3=\dfrac{\left(\dot{y}_M-\dot{y}\right)\cdot\cos\phi_3-\left(\dot{x}_M-\dot{x}\right)\cdot\sin\phi_3}{d_3} \\ \varepsilon_2=\dfrac{\ddot{y}\cdot\cos\phi_2-\ddot{x}\cdot\sin\phi_2}{d_2} \\ \varepsilon_3=\dfrac{\left(\ddot{y}_M-\ddot{y}\right)\cdot\cos\phi_3-\left(\ddot{x}_M-\ddot{x}\right)\cdot\sin\phi_3}{d_3} \end{cases} \tag{4}$$

Enter the III values in II and recalculate II which become II '. Then with III in III is recalculated and III becomes III '. At small differences between the values III and III 'the iterative process stops, otherwise it must continue resulting II' 'and III' ', etc.

Important notice!

When the moments of the actuators are unknown (for example, there are used motorbikes, which are not technically familiar and therefore can not determine the mean or exact value of the torque generated by the angular speed imposed), or not know exactly the mass parameters of the elements and/or the external loads, one can use the simple or direct dynamic kinematics, without the set 0 (it is practically renounced to the dynamic relations, Lagrange) using only the relations in sets I, II and III, but also with known angular speeds.

Normally, the positions with the set of relations I are calculated, then the linear velocities and accelerations with the set II of existing relations are determined, knowing the desired angular speeds of the actuators and for their initial angular accelerations considering the values 0, only in set II.

Then the exact angular speeds and the exact angular accelerations from the calculations made with the set of relationships III will then result, at which point it automatically follows at least one iteration, recalculating II 'and III'.

It is good in this situation to carry out an iteration or even two, even if the convergence is strong enough. Thus, II ', III' 'and maybe even II' 'and III' 'are also obtained.

Discussion

The masses and forces (exterior and interior) acting on the kinematic chain directly influence the average angular velocities of the balanced cinematic chain elements, ω_2, ω_3. These determine the real, dynamic kinematics of the mechanism by the systems of equations II and III, directly influencing the values of linear and angular velocities and accelerations for each point and element of the chain in each of its positions.

The actual angular accelerations of the two elements of the chain $\varepsilon_{2*}, \varepsilon_{3*}$ in each position obtained with III', or III'', or even III''', cause variations in actuator moments, according to the relationships given by the system (5), variations which immediately change and the average input angular velocities ω_2, ω_3 bringing them to the instantaneous values $\omega_{2'}$, $\omega_{3'}$ determined from the characteristic diagrams of the two actuators (for actuator 2, the angular velocity removed from its characteristic diagram according to the instantaneous moment of the motor torque will be passed directly as the new angular velocity $\omega_{2'}$, but for the motor 3 according to the instantaneous calculated value of the motor moment Mm3 will determine from the characteristic diagram the instantaneous value of the angular speed of the actuator 3 $\dot{\theta}_{,}$, which will calculate the new instantaneous speed value $\omega_{3'} = \omega_{2'} + \dot{\theta}_{,}$:

$$\begin{cases} M_{m_2} = J_{O_2}^* \cdot \varepsilon_2 \\ M_{m_3} = J_{O_3} \cdot \varepsilon_3 \\ M_{m_2} = \left(m_2 \cdot s_2^2 + m_{II} \cdot \rho_2^2 + m_{3'} \cdot d_2^2\right) \cdot \ddot{\phi}_{20} \\ M_{m_3} = \left(m_s \cdot d_3^2 + m_3 \cdot s_3^2 + m_{III} \cdot \rho_3^2\right) \cdot \ddot{\phi}_{30} \end{cases} \quad (5)$$

It is possible to recalculate the relations of the systems II and III (which pass into II * and III * respectively) for each position of the mechanism (the open-plan cinematic chain), introducing in the linear speed and acceleration system II (for angular velocities and accelerations) values $\omega_{2'}, \omega_{3'}$ and $\varepsilon_{2*}, \varepsilon_{3*}$. With II * is recalculated III *.

It is thus obtained from III * exact dynamic values, actual velocities and angular accelerations, of the mechanism (planar, open, balanced). Here again, several iterations can be performed (for example, using a computing program).

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3-Contract research. GR 69/10.05.2007: NURC in 2762; theme 8: Dynamic analysis of mechanisms and manipulators with bars and gears.

4-Labor contract, no. 35/22.01.2013, the UPB, "Stand for reading performance parameters of kinematics and dynamic mechanisms, using inductive and incremental encoders, to a Mitsubishi Mechatronic System" "PN-II-IN-CI-2012-1-0389".

Author’s Contributions

This section should state the contributions made by each author in the preparation, development and publication of this manuscript.

Ethics

Authors should address any ethical issues that may arise after the publication of this manuscript.

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