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Modeling of Transmission Mechanisms through Tendons

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Abstract

The implementation of mechanisms for the emulation of tendons get supported thanks to the significant advantage that they represent in the aspects of weigh and costs, with the need of considerate the disadvantage in terms of maneuverability and its strict restriction in terms of work space. Ref. [1] Thanks to this, it can be developed open kinematic chains free of extra weight that brings with it the disposition of the actuator on each degree of freedom, which is ideal specially on movement mechanisms such as: hands and articulated fingers. Ref. [2,3] From there lies the need of prototypes design with, as a principal foundation, the transmissions of force that the tendon is characteristic for. With the last thing, in the presented work it is described the mathematical model of a transmission mechanism N and N+1 type, based in the tendon's behavior, as the application of State feedback controllers with observer. With the purpose of finally conclude about the obtained results and the advantages of the different types of transmissions Ref. [4].

Keywords: Actuator, Kinematic Chains, Elasticity Systems, Transmission Systems, Tendons.

INTRODUCTION

Now days, the robotic has focused on the emulation of human behaviors for the task performance. With special emphasis in the development of mechanisms based on a hand and fingers morphology, which are main organs in the reception and reaction of tactile stimulation, besides the bases that they provide for the development of clamping mechanisms. Ref. [5] Evident in the development such as Bank's Ref [6] that show the design of a finger with movement transmission through wires and equipped with sensor to provide the prototype with a sensorial capacity.

The most part of the systems of movement transmission are based in mechanisms N or N+1 types, where N represents the number of degrees of freedom. Ref. [7] The N configuration is based in the transmission of rotating energy of the loads, through tension wires (tendons); and usually they possess on their configuration relaxation springs that avoid the reduced contractions of the system. Ref. [8] Meanwhile in the N+1 configuration, each one of the rotation axes of the load are connected to two tension wires in charge of the elongation and flection respectively. Ref. [9, 10]

The above is the base of the design of bar type transmission systems or by pulleys, the first type is of ease implementation but with movement limitations because the flection movements are produced at the same time on the joints of the mechanism, reducing the maneuverability. Meanwhile in the transmission by pulleys, the wires and placed in fixed points avoiding sliding and producing harmonic movements. Ref. [11, 12]

Besides of the mechanical design of the clamping prototypes, must be considered the elements that allow the generating of movement such as the defined actuators as components which finality is based in the actions transmission to the elements that make up the system, from the input signals that varies in behalf of the actuator's nature. Ref. [13] Nowadays in the robotic field, the most used actuators transmit the mechanical force using pneumatic energy, hydraulic or electric, causing an effect on linear and angular movements. Ref. [14]

The presented work will be structured as: Section 1, it will be developed the mathematical descriptions of the mechanisms to implement, as the representation of the State Space variables. Section 2, it will be developed the analysis of results and the open loop simulations of the mechanisms, and by this analyze their behavior. Finally, in section 3 it will be concluded about the developed models, their configurations and obtained results in the simulation of the open loop system.

TRANSMISSON MECHANISMS

For the development of the presented work we consider the structure showed in Fig. 1, which describes the main configuration used in transmissions N and N+1 types, and which will be the base of the mathematical models. Ref. [12]

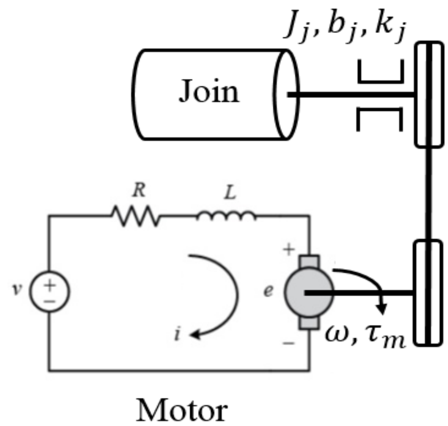

Figure 1. Join-motor coupling scheme

A. Mathematical model of a motor controlled by armor

The actuator set up to generate the movement described in figure 1, has the characteristic to have its electronic part modeled as presented in (1). Ref. [15]

$$v(t) = R * i(t) + L * \frac{di(t)}{dt} + e(t) \qquad (1)$$

Besides, it requires the implementation of a mechanic and electric relation, with the objective of getting the torque that will be applied to the mechanism for its movement, the relation is described in (2) and (3).

$$\tau_m(t) = K_e * i(t) \qquad (2)$$

$$e(t) = K_m * w(t) \qquad (3)$$

Replacing (2) and (3) in (1) we get the (4), that represents the existent relation between the join and the actuator.

$$\frac{di_a(t)}{dt} = \frac{1}{L} v_a(t) - \frac{R_a}{L} * i_a(t) - \frac{K_m}{L} * w(t) \qquad (4)$$

B. N type mechanism with elongation spring

The mechanism N type presented in Fig. 2 has in its configuration a spring at the join or load, and it oversees generating the elongation movement after the motor generates flection on itself. The movement flection is giving from a torque (τ_m) applied over tension wire placed between the load and the motor. Ref. [7]

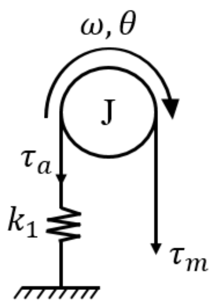

Figure 2. N type mechanism scheme with elongation spring

From Fig. 2 we get the force diagram over the join, from which we get the mathematical descriptions presented on (5) and (6).

$$J_j \cdot \ddot{\theta} + b_j \cdot \dot{\theta} + k_j \cdot \theta = R_j \cdot (\tau_m - \tau_a) \qquad (5)$$

$$\tau_a = k_1 \cdot x \quad \therefore \quad x = R_j \cdot \theta \quad \Rightarrow \quad \tau_a = k_1 \cdot R_j \cdot \theta \qquad (6)$$

Replacing (2), (3) and (6) on (5), we get the mathematical description in (7), which describe the behavior of the mechanism presented in Fig. (2).

$$\ddot{\theta} = \frac{R_j k_e}{J_j} i(t) - \frac{k_1 R_j^2}{J_j} \theta(t) - \frac{b_j}{J_j} \dot{\theta} - \frac{k_j}{J_j} \theta \qquad (7)$$

Finally, through the control system, it is defined the matrices of the Space-State representation, following the proposed form presented in (8), with the will of getting (9).

$$\dot{x} = A \cdot x + B \cdot u$$
$$y = C \cdot x + D \cdot u \qquad (8)$$

$$A = \begin{bmatrix} 0 & 0 & 1 \\ 0 & -\frac{R}{L} & -\frac{k_m}{L} \\ -\frac{(k_1 R^2 + k_j)}{J_j} & \frac{R k_e}{J_j} & -\frac{b_j}{J_j} \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ \frac{1}{L} \\ 0 \end{bmatrix} \qquad (9)$$
$$C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \qquad D = [0]$$

C. N type mechanism with elongation and flection springs

The N type mechanism presented in Fig. 3, has, as the last one, a spring coupled to the load, it is in charge of generating the elongation movement after the motor generates flection on itself through the tension wire, which in these cases, it poses an elasticity coefficient that needs to be considerate in the mathematical model because of the fact that with it the friction effect is reduced on the mechanism. Ref. [8]

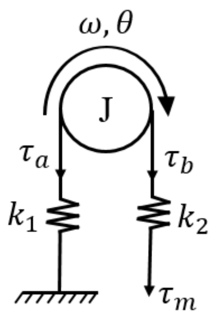

Figure 3. N type mechanism scheme with elongation and flection springs

From Fig. 3 we get the force diagram over the load, from which we get the mathematical descriptions presented in (10), (11) and (12).

$$J_j \cdot \ddot{\theta} + b_j \cdot \dot{\theta} + k_j \cdot \theta = R_j \cdot (\tau_a - \tau_b) \qquad (10)$$

$$\tau_a - \tau_m = k_2 \cdot R_j \cdot \theta \quad \Rightarrow \quad \tau_a = k_2 \cdot R_j \cdot \theta + \tau_m \qquad (11)$$

$$\tau_b = k_1 \cdot R_j \cdot \theta \qquad (12)$$

Replacing (2), (11) and (12) on (10), we get the mathematical description in (13), which describe the behavior of the mechanism from Fig. 3.

$$\ddot{\theta} = \frac{R_j k_e}{J_j} i(t) + \frac{k_2 R_j^2 - k_1 R_j^2 - k_j}{J_j} \theta - \frac{b_j}{J_j} \dot{\theta} \qquad (13)$$

Finally, through the control system, it is defined the matrices of the Space-State representation, following the proposed form presented in (8), with the will of getting (14).

$$A = \begin{bmatrix} 0 & 0 & 1 \\ 0 & -\frac{R}{L} & -\frac{k_m}{L} \\ \frac{k_2R_j^2 - k_1R_j^2 - k_j}{J_j} & \frac{Rk_e}{J_j} & -\frac{b_j}{J_j} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ \frac{1}{L} \\ 0 \end{bmatrix} \quad (14)$$

$$C = [1 \quad 0 \quad 0] \qquad D = [0]$$

D. N+1 type simple mechanism

The mechanism N+1 type showed in the Fig. 4, has the characteristic of having two tension wires that are in charge of elongation and flection, which are controlled by the actuator. From there we define that for the movement, the torque given by the motor must be positive for one tension wire and negative for the other one [9].

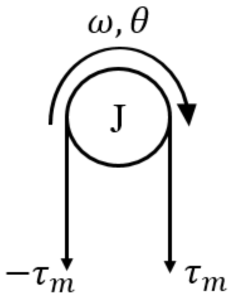

Figure 4. N+1 type simple mechanism scheme

From Fig. 4 we get the force diagram over the load, from which we get the mathematical descriptions described in (15) and (16).

$$J_j \cdot \ddot{\theta} + b_j \cdot \dot{\theta} + k_j \cdot \theta = R_j \cdot (\tau_m - (\tau_m)) \quad (15)$$

$$J_j \cdot \ddot{\theta} + b_j \cdot \dot{\theta} + k_j \cdot \theta = 2 \cdot R_j \cdot \tau_m \quad (16)$$

Replacing (2) on (16), we get the mathematical description in (17), which describes the behavior of mechanism presented in Fig. 4.

$$\ddot{\theta} = \frac{2R_jk_e}{J_j}i(t) - \frac{b_j}{J_j}\dot{\theta} - \frac{k_j}{J_j}\theta \quad (17)$$

Finally, through the control system, it is defined the matrices of the Space-State representation, following the proposed form presented in (8), with the will of getting (18).

$$A = \begin{bmatrix} 0 & 0 & 1 \\ 0 & -\frac{R}{L} & -\frac{k_m}{L} \\ -\frac{k_j}{J_j} & \frac{2R_jk_e}{J_j} & -\frac{b_j}{J_j} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ \frac{1}{L} \\ 0 \end{bmatrix} \quad (18)$$

$$C = [1 \quad 0 \quad 0] \qquad D = [0]$$

E. N+1 type mechanism with elongation and flection springs

The mechanism N+1 type presented in the figure 5 has two tension wires in charge of the elongation and flection, and both of them have an elasticity coefficient, which must be taken in consideration in the mathematical model, because of the reason that they reduce the friction effect. Besides, it must be taken in mind that, as the mechanism in Fig. 5, this one possesses the same actuator for the movement generation. Ref. [10]

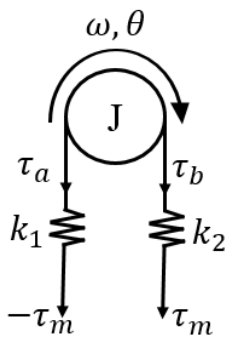

Figure 5. N+1 type mechanism scheme with elongation and flection springs

From Fig. 5 we get the force diagram over the load, from which we get the mathematical descriptions described in (19), (29) and (21).

$$J_j \cdot \ddot{\theta} + b_j \cdot \dot{\theta} + k_j \cdot \theta = R_j \cdot (\tau_a - \tau_b) \quad (19)$$

$$\tau_a - \tau_m = k_2 \cdot R_j \cdot \theta \quad \Rightarrow \quad \tau_a = k_2 \cdot R_j \cdot \theta + \tau_m \quad (20)$$

$$\tau_b - \tau_m = k_1 \cdot R_j \cdot \theta \quad \Rightarrow \quad \tau_b = k_1 \cdot R_j \cdot \theta - \tau_m \quad (21)$$

Replacing the equation on equation (19), we get the mathematical description in (22), which describes the mechanism behavior in the Fig. 5.

$$\ddot{\theta} = \frac{2R_jk_e}{J_j}i(t) + \frac{k_2R_j^2 - k_1R_j^2 - k_j}{J_j}\theta - \frac{b_j}{J_j}\dot{\theta} \quad (22)$$

Finally, through the control system, it is defined the matrices of the Space-State representation, following the proposed form presented in (8), with the will of getting (23).

$$A = \begin{bmatrix} 0 & 0 & 1 \\ 0 & -\frac{R}{L} & -\frac{k_m}{L} \\ \frac{k_2R_j^2 - k_1R_j^2 - k_j}{J_j} & \frac{2R_jk_e}{J_j} & -\frac{b_j}{J_j} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ \frac{1}{L} \\ 0 \end{bmatrix} \quad (23)$$

$$C = [1 \quad 0 \quad 0] \qquad D = [0]$$

ANALYSIS OF RESULTS AND DISCUSSION

The mathematical models described before show the behavior of the tension wires applied movement transmission either N or N+1 type. From which the open loop simulation with a step entry with 2π value for the N type, and 2π and -2π for N+1 type. This with the objective of determine which are the main behaviors and its functionality characteristics. Besides, we establish the simulation parameters in the table 1.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
k_j	$2 \quad N/m$
k_1	$1 \quad N/m$
k_2	$1 \quad N/m$
J_j	$3 \quad Kg/m^2$
b_j	$3 \quad \mu \cdot N$
R_j	$0.02 \quad m$
R	$1 \quad \Omega$
L	$10 \cdot 10^3 \quad H$
k_e	$1 \cdot 10^6 \quad Nm/A$
k_m	$1 \cdot 10^6 \quad Vs/rad$

For the above, we get the graphics presented in figure 6 for the mechanism 1, the one in Fig. 7 for the mechanism 2, Fig. 8 for the mechanism 3 and the one presented in Fig. 9 for the mechanism 4.

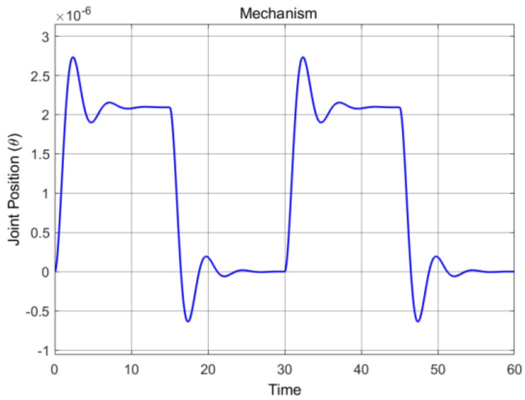

Figure 6. N type mechanism response with elongation spring

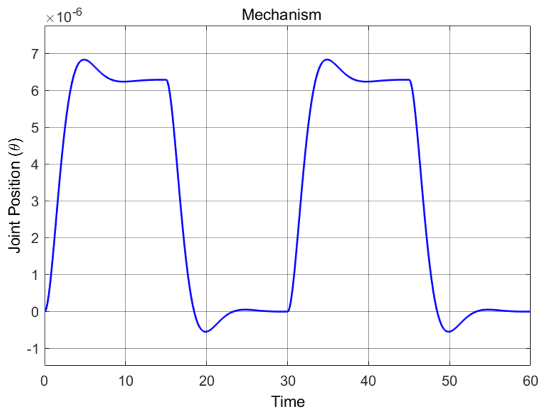

Figure 7. N type mechanism response with elongation and flection springs

In Fig. 6 and 7 it can be observed the N type mechanism, whose behavior varied, the reason for this was that, in the first one it is placed only one elongation spring that forces a direct effect on the position's behavior of the join, since the motor must break the initial inertia of the join plus the resistance exercised for the spring, this causes the initial oscillation in the mechanism's response. Besides of it, in Fig. 7, it can be observed a system in which the motor must break the initial inertia of two springs plus the inertia of the join, but, because of the existence of an elongation spring and a flection spring, their forces work opposite to each other causing their effects as zero in the finale response of the system.

In Fig. 8 and 9, it is observed a look alike behavior, since as said it before, the existence of two spring that work opposite to each other, the forces null each other, and this can be reflected in the response described in the figures.

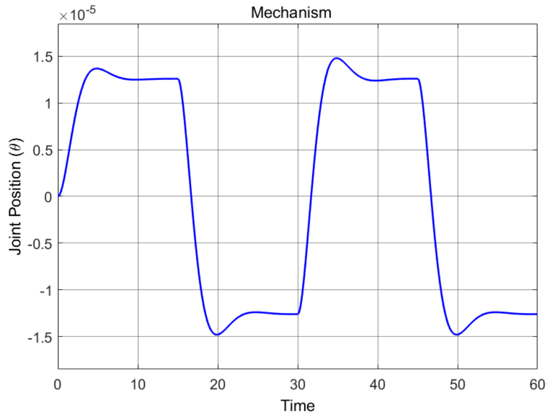

Figure 8. N+1 type simple mechanism response

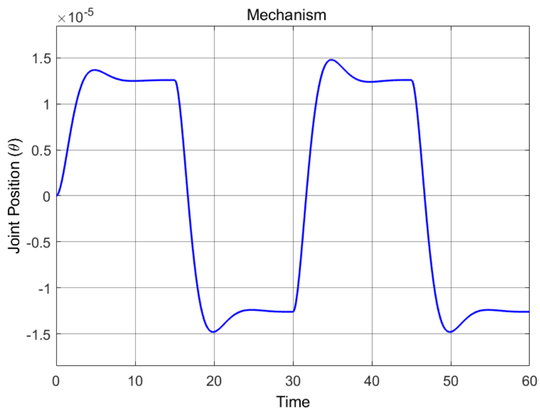

Figure 9. N+1 type simple mechanism response with elongation and flection springs

CONCLUSION

At the moment of developing the mathematical models and the open loop simulations of the mechanisms described in previous chapters, it is observed that the N type mechanisms get affected by the effects of the elasticity system applied on the tension wires in comparison to the N+1 type systems.

Taking in to account that the N+1 types have the advantage of having the possibility of being controlled in the two directions of movement because of the two springs.

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