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Florin Bausic, Alexandru Cosmescu, Filip Gărdăreanu

Stability Analysis for Hand-arm-forearm Dynamic System

In this paper we propose a model with four degrees of freedom for hand-arm-forearm dynamic system. Using experimental data from [9] by means of the Simulink program, is built block diagram to simulate the dynamic system motion and phase diagrams are drawn by using Matlab. From the interpretation of these diagrams result, for a set of parameters (m, c, k, F_0, ω), stable moves for the hand-arm-forearm dynamic system.

Keywords: *stability, dinamic system, Simulink, Matlab*

1. The dynamic model proposed

For the dynamic hand-arm-forearm system is proposed, in Figure 1, a model with four degrees of freedom.

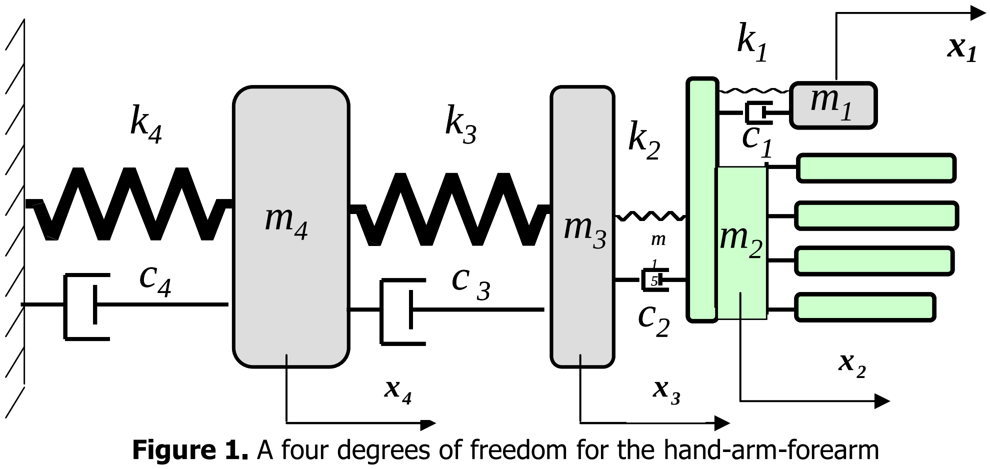

Figure 1. A four degrees of freedom for the hand-arm-forearm dynamic system

m_1-thumb; m_2-palm and four fingers; m_3-forearm; m_4-arm

2. Determination of differential equations of motion

Using Lagrange's equations (II), the differential equations of motion in matrix form are:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F\} \tag{1}$$

where:

$$[M]=\begin{bmatrix} m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \\ 0 & 0 & m_3 & 0 \\ 0 & 0 & 0 & m_4 \end{bmatrix}$$ is the matrix of inertia (2)

$$[K]=\begin{bmatrix} k_1 & -k_1 & 0 & 0 \\ -k_1 & k_1+k_2 & -k_2 & 0 \\ 0 & -k_2 & k_2+k_3 & -k_3 \\ 0 & 0 & -k_3 & k_4 \end{bmatrix}$$ is the stiffness matrix (3)

$$[C]=\begin{bmatrix} c_1 & -c_1 & 0 & 0 \\ -c_1 & c_1+c_2 & -c_2 & 0 \\ 0 & -c_2 & c_2+c_3 & -c_3 \\ 0 & 0 & -c_3 & c_4 \end{bmatrix}$$ is the damping matrix (4)

$$\{F\}=\begin{Bmatrix} -F_O \\ 0 \\ 0 \\ 0 \end{Bmatrix} \sin \omega t$$ is the column vector of the excitation force (5)

Matrix differential equation (1) is developed being obtained the system:

$$\begin{cases} m_1\ddot{x}_1+c_1\dot{x}_1+k_1x_1-c_1\dot{x}_2+k_1x_2=F_0 \sin \omega t \\ m_2\ddot{x}_2-c_1\dot{x}_1-k_1x_1+(c_1+c_2)\dot{x}_2+(k_1+k_2)x_2-k_2x_3 \\ m_3\ddot{x}_3-c_2\dot{x}_2-k_2x_2+(c_3+c_4)\dot{x}_3+(k_3+k_4)x_3-c_3\dot{x}_4+k_3x_3 \\ m_4\ddot{x}_4-c_3\dot{x}_3-k_4x_3+c_4\dot{x}_4+k_4x_4 \end{cases} \tag{6}$$

To determine the motion and speed laws, in order to analyze the dynamic stability of the system, will use Simulink.

For this purpose the differential equations system (6) to rewrite as follows.

3. Using Simulink software

By rewriting the system of equations (6) result:

$$\begin{cases} \ddot{x}_1 = \dfrac{1}{m_1}\left[-c_1\dot{x}_1 - k_1x_1 + c_1\dot{x}_2 + k_1x_2 - F_0 \sin\omega t\right] \\ \ddot{x}_2 = \dfrac{1}{m_2}\left[c_1\dot{x}_1 + k_1x_1 - (c_1+c_2)\dot{x}_2 - (k_1+k_2)x_2 + k_2x_3\right] \\ \ddot{x}_3 = \dfrac{1}{m_3}\left[c_2\dot{x}_2 + k_2x_2 - (c_3+c_4)\dot{x}_3 - (k_3+k_4)x_3 + c_3\dot{x}_4 - k_3x_3\right] \\ \ddot{x}_4 = \dfrac{1}{m_4}\left[c_3\dot{x}_3 + k_4x_3 - c_4\dot{x}_4 - k_4x_4\right] \end{cases} \tag{7}$$

For each of the four differential equations of the system (7), will compose one subsystem with predefined blocks from Simulink library.

For example, the differential equation:

$$\ddot{x}_1 = \frac{1}{m_1}\left[-c_1\dot{x}_1 - k_1x_1 + c_1\dot{x}_2 + k_1x_2 - F_0 \sin\omega t\right] \tag{8}$$

in Simulink have a block diagram shown in Figure 2.

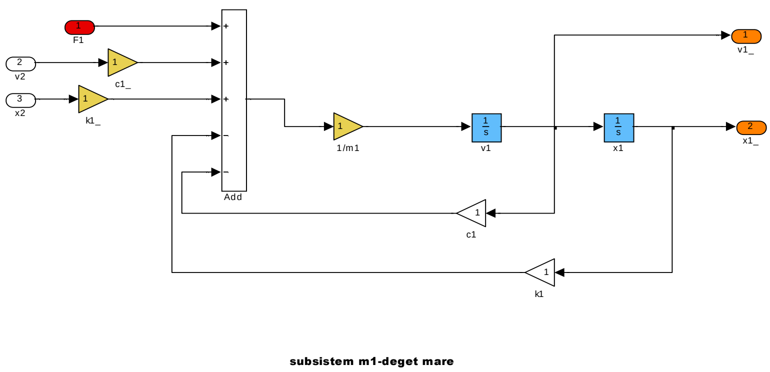

Figure 2. Simulink block diagram of the subsystem m_1-thumb

We obtain similar block diagram for the other three differential equations.

All these block schemes it encapsulates and connects in a block diagram of the whole hand-arm-forearm system dynamic, shown in Figure 3.

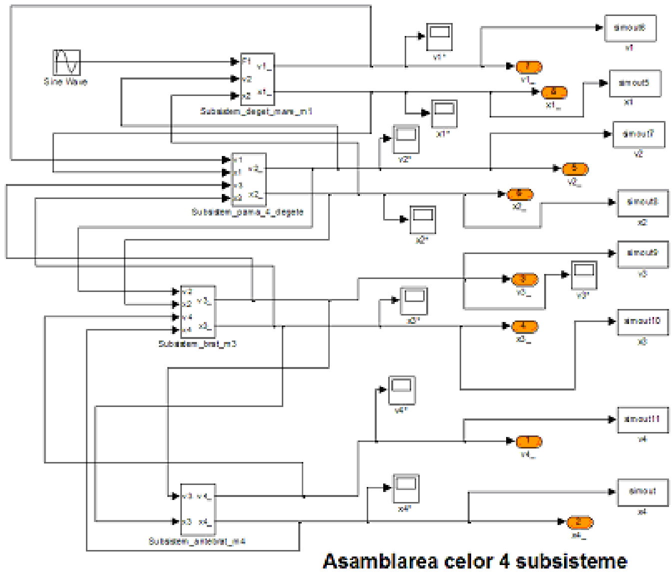

Figure 3. Block diagram of the hand-arm-forearm dynamic system

4. The simulation results

Next figure was drawn the speed variation depending on displacement under a sinusoidal disturbance forces acting on the thumb, using experimental data from [9].

Four graphics were obtained, namely:

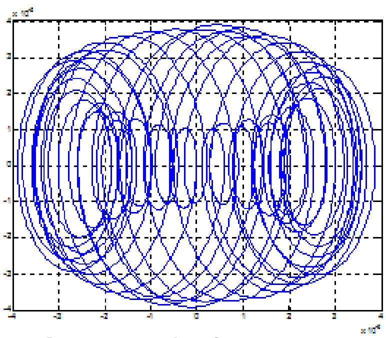

Figure 4. The forearm state space diagram

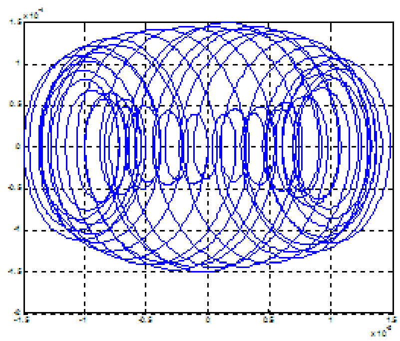

Figure 5. The arm state space diagram

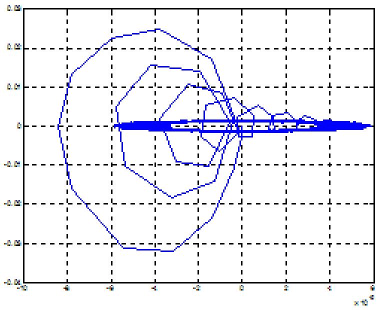

Figure 6. The palm state space diagram

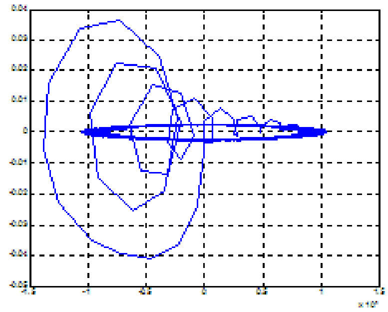

Figure 7. The thumb state space diagram

5. Conclusions

From the analysis of four displacement speed charts under the force $F_0 \sin\omega t$ and considering into account all the elements that make up the damping system finds that all these representations are cyclic closed curves.

From the analysis of four diagrams, displacement speed under the disruptive force $F_0 \sin\omega t$ and taking into account the damping of all the elements that make up system, notes that all these representations are cyclic closed curves.

According to chaos theory, if a representation in space of states (velocity, displacement) is a closed cycle curve, then the system is stable.

This method of simulation has a future application the study of manipulators stability installed or mounted on a vehicle carrier similar to those shown in the figure below:

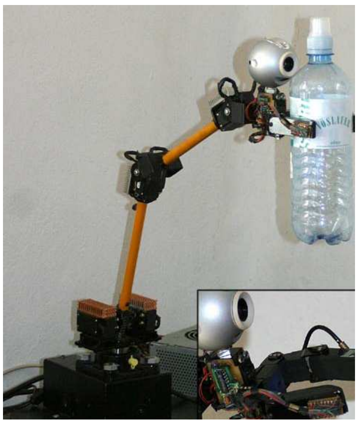

Figure 8. Exemples of manipulators

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Adresses:

- Professor PhD, eng. Florin Bausic, The Department of Technical Mechanics and Mechanisms, Technical University of Civil Engineering, Bucharest, Faculty of Technological Equipment, Calea Plevnei no. 59, code 010223, sector 1, Bucharest, florin.bausic@utcb.ro
- Eng. Alexandru Cosmescu - Advanced Mechanical Systems (Master, 2nd year of study), Faculty of Technological Equipment, Calea Plevnei no. 59, code 010223, sector 1, Bucharest;
- Filip Gărdăreanu - 2nd year of study, Faculty of Technological Equipment, Calea Plevnei no. 59, code 010223, sector 1, Bucharest.