Vibratory Analysis of a Robotic Hand

Ştefan Dumitru, Andrei Craifaleanu(✉), and Roxana Alexandra Petre

University "Politehnica" of Bucharest, Bucharest, Romania

Abstract. The paper presents an anthropomorphic robotic hand which is to become part of a robot manipulator. The real human hand is a complex mechanism, made of 27 bones, out of which 19 can move relative to each other, therefore creating a mechanical system with 25 degrees of freedom. The practical implementation of a mechanical hand with such a high number of degrees of freedom causes major technological difficulties, hence robotic hands are often made in simpler configurations than those of a human hand. The studied device presented in the paper is such a simplified model. The functionality of the device imposes certain requirements on the accuracy of motions that can be affected by vibrations induced by various mechanical interactions. By considering first the fingers as independent systems, and, afterwards, the entire hand mechanism, with five fingers, a number of eigenfrequencies and eigenmodes of the device are determined. The paper presents also the variation curves showing the influence of the system configuration on the eigenfrequencies.

Keywords: Anthropomorphic robotic hand · Eigenfrequency · Eigenmode · Vibration

1 Introduction

The current trend of industrial process automation requires extensive use of robots with different functional characteristics. Among them, the anthropomorphic robots and, in particular, the robotic hands, stand out due to their versatility.

The term "robot" was created in 1921 by Karel Čapek, a Czechoslovakian playwriter for his play "Rossum's Universal Robots", where humans create mechanical devices to serve as workers. The term "robotics" was introduced by science fiction author Isaac Asimov in his 1942 short story "Runaround", where he formulated his concept of "The Three Laws of Robotics" [1–3].

By the year 1950 engineers were developing machines to handle difficult or dangerous repetitive tasks for both defense and consumer manufacturing. Since robots were meant to replicate the pattern of motions that a human would make while lifting, pulling, pressing, or pushing, some of the designs were based on the anatomical structure of a human arm [1–3].

The functionality of these devices is still conditioned by the precision of the mechanical motions, which can be severely affected by the vibrations induced by various mechanical interactions [4–7].

N. Herisanu and V. Marinca (eds.), *Acoustics and Vibration of Mechanical Structures – AVMS-2021*, Springer Proceedings in Physics 274,
https://doi.org/10.1007/978-3-030-96787-1_24

This paper studies the vibrations of an anthropomorphic robotic hand that is to become part of a robot manipulator, intended for repetitive mechanical operation, for current use (Fig. 1).

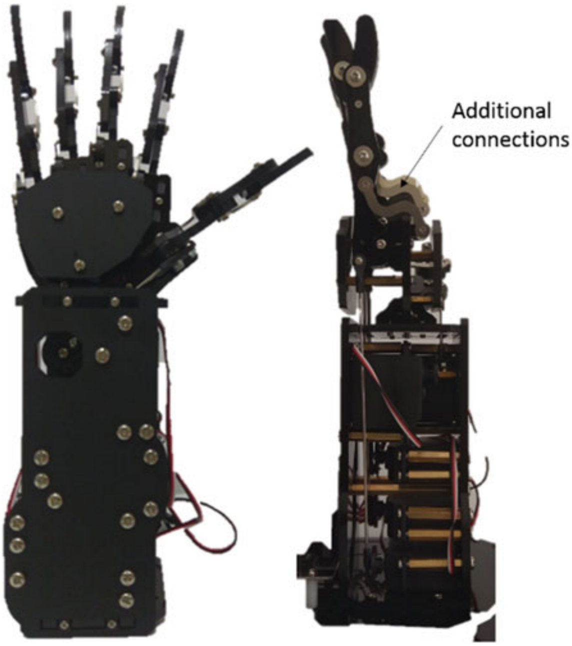

Fig. 1. Robotic hand.

The robotic hand is modeled as a system of elastic bodies with various geometric configurations and is analyzed from the vibratory point of view, using the CATIA V5 software.

2 Configuration of the Robotic Hand

The real human hand is a complex mechanism, made of 27 bones, out of which 19 can move relative to each other, therefore creating a mechanical system with 25 degrees of freedom [8, 9].

The practical implementation of a mechanical hand with a high number of degrees of freedom leads to major technological difficulties, such as: increasing the complexity of the system, using a high number of actuators and electronic control components, increasing the system mass, and need of large amounts of energy in order to operate.

As a result, robotic hands are often made in simpler configurations than those of a human hand, with a smaller number of mobilities, the motion of certain elements being correlated, by using additional connections. Such devices cannot perform motions as complex as those of a real hand, but they can provide a functional configuration close to the real one, enough for a large number of practical applications.

The studied device is such a simplified model, with only five mobilities (Fig. 2). The phalanges are modeled as elastic bodies connected by hinge joints.

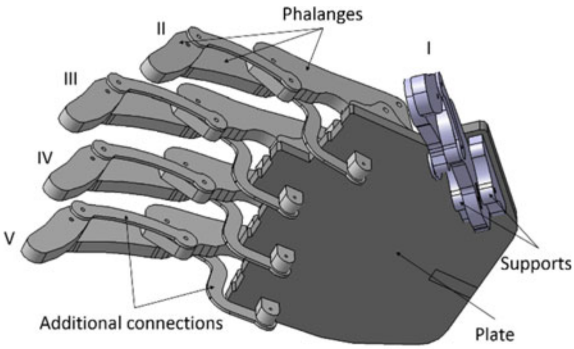

Fig. 2. Robotic hand 3D model.

The constructive characteristics of the studied robotic hand are presented in Fig. 3, while the material characteristics are given in Table 1.

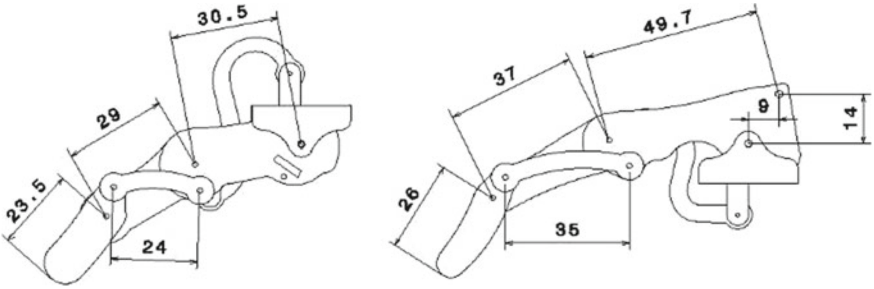

Fig. 3. Constructive characteristics [mm] of finger I (left) and fingers II–V (right).

Table 1. Material characteristics of the robotic hand elements

Element	Material	Density (kg/m^3)	Young's modulus (N/m^2)	Poisson ratio
Phalanges, supports, plate	Wood	610	1.4×10^{10}	0.45
Additional connections	Duralumin	2710	7×10^{10}	0.346

3 Numerical Study and Results

The free vibrations of the robotic hand were analyzed using the CATIA V5 software, separately for the following case studies:

1. finger I (thumb), considered as an independent system (Fig. 4—left);

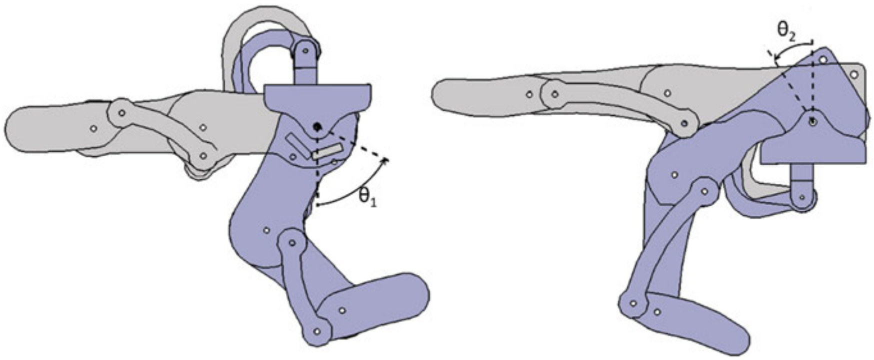

Fig. 4. Finger I (left) and fingers II–V (right), considered as independent systems.

2. one of the fingers II–V, which are presumed identical, considered as an independent system (Fig. 4—right);
3. the whole hand, considering the fingers fixed on the plate that models the carpals and metacarpals (Fig. 2).

   All three cases were analyzed for two configurations (Fig. 4), expressed by angle θ_1 for the thumb and θ_2 for the other finger:

   - extended phalanges (light gray)—$\theta_1 = 0°$, $\theta_2 = 0°$.
   - flexed phalanges (dark gray)—$\theta_1 = 64°$, $\theta_2 = 32°$.

Supplementary, the fingers as independent systems, were also considered in seven intermediate configurations between the above two, with the steps $\Delta\theta_1 = 8°$ and $\Delta\theta_2 = 4°$, respectively.

Table 2 presents the first five eigenfrequencies[10] of the extended and flexed configurations.

Figure 5 illustrates the variation of the first two eigenfrequencies (f_1 and f_2) of the thumb and of the other finger, considered as independent systems, with respect to angle θ_1 and θ_2, respectively.

Figures 6, 7, 8, 9, 10, 11, 12 and 13 illustrate some of the determined eigenmodes.

Table 2. First five eigenfrequencies (Hz)

Eigenfrequency	f_1	f_2	f_3	f_4	f_5
Extended finger I	433	607	1291	2208	2351
Extended finger II–V	344	559	1864	2548	2631
Extended hand	298	298	298	298	371
Flexed finger I	557	634	1259	1384	1891
Flexed finger II–V	396	641	1203	2100	2343
Flexed hand	338	338	338	338	414

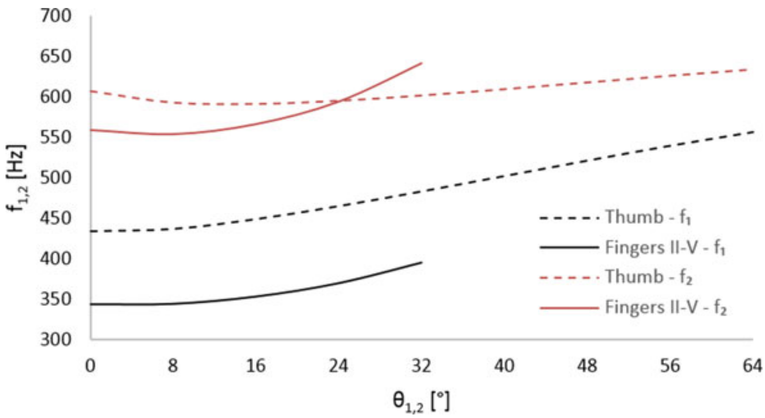

Fig. 5. Variation of the first two eigenfrequencies with respect to angles θ_1 and θ_2.

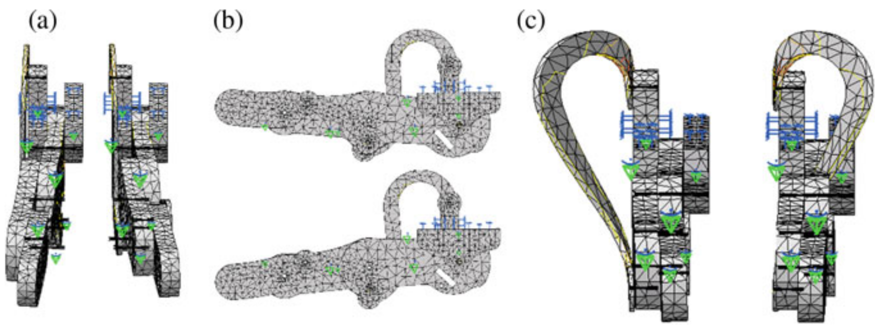

Fig. 6. Extended finger I (thumb)—eigenmodes 1, 2, 3.

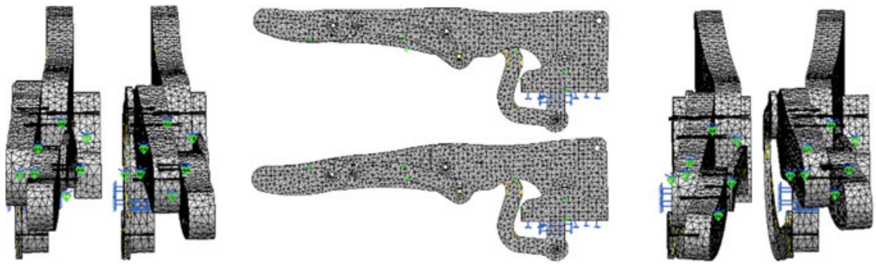

Fig. 7. Extended fingers II–V—eigenmodes 1, 2, 3.

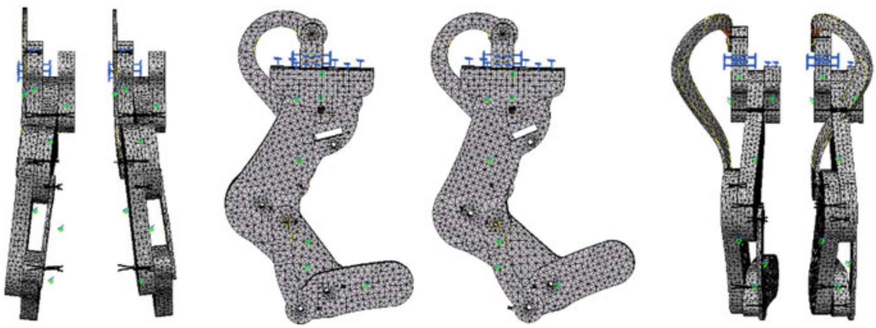

Fig. 8. Flexed finger I (thumb)—eigenmodes 1, 2, 3.

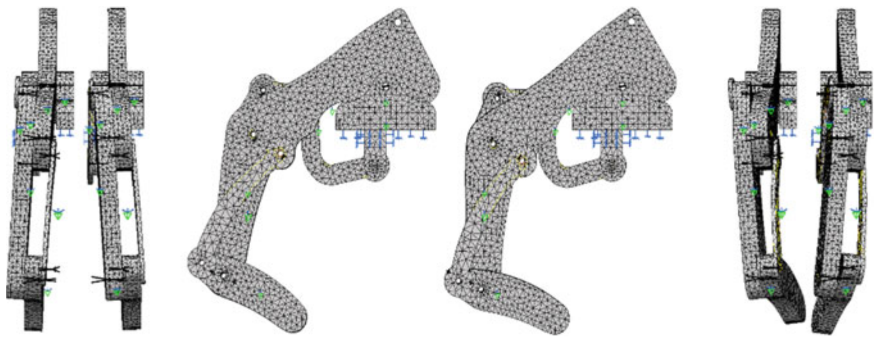

Fig. 9. Flexed fingers II–V—eigenmodes 1, 2, 3.

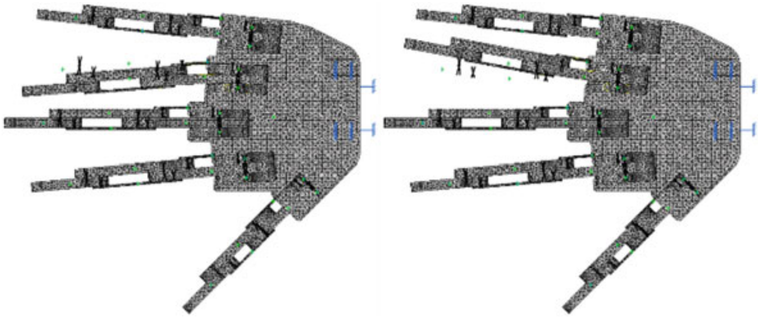

Fig. 10. Extended hand—eigenmode 1.

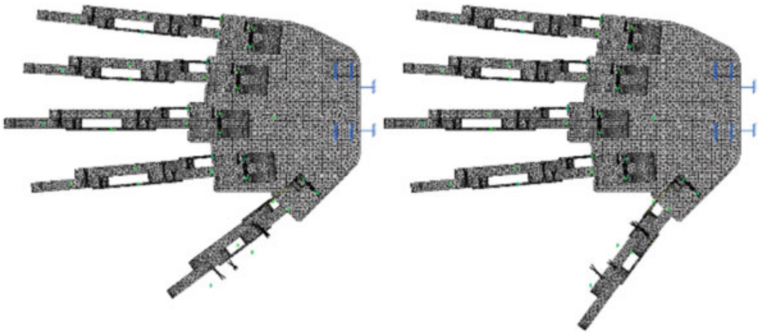

Fig. 11. Extended hand—eigenmode 5.

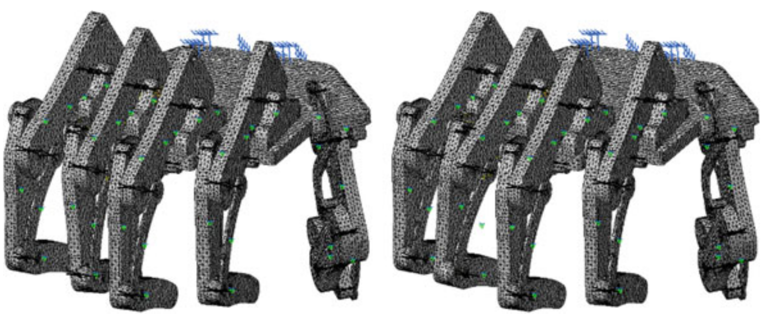

Fig. 12. Flexed hand—eigenmode 1.

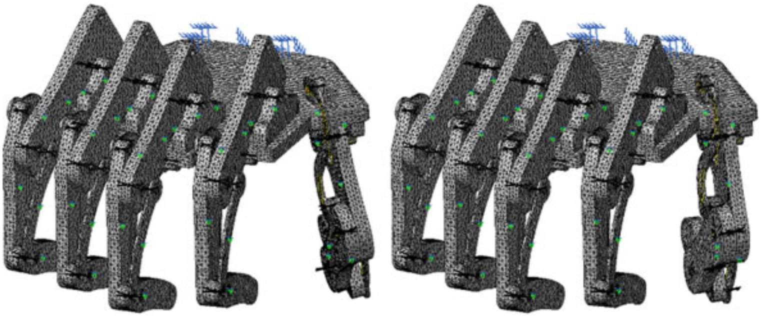

Fig. 13. Flexed hand—eigenmode 5.

4 Conclusions

The vibratory analysis of the anthropomorphic robotic hand using the CATIA V5 software leads to the following conclusions:

1. the first eigenmode of all five fingers, considered as independent systems, is a bending one, in a plane parallel to that of the plate;
2. the second eigenmode of all five fingers, considered independent systems, is a bending one in a plane perpendicular to that of the plate;
3. the higher eigenmodes show coupled deformations and different aspects from one configuration to another; in some cases, the oscillations of the additional connections are prevailing;
4. the first two eigenfrequencies are higher for finger I (thumb), than for fingers II–V, which can be explained by the size difference between the first finger, which is smaller, and the other four. This is not valid for the higher modes, which can be explained by their different shape, from one configuration to another;
5. the first two eigenfrequencies, generally, tend to increase with the flexing degree (expressed by parameters θ_1 and θ_2, respectively), which is explained by the smaller general size of the system. This property is also not valid for higher eigenmodes;
6. for the first four eigenmodes of the hand, the bending of fingers II–V in a plane parallel to that of the plate is predominant, and the corresponding eigenfrequencies are very close in terms of values (coinciding at the displayed precision), due to the identical characteristics of the respective fingers; these modes correspond to the first vibration mode of fingers II–V, considered as independent systems;
7. for the fifth eigenmode of the hand, the bending of finger I (thumb) in a plane parallel to that of the plate is predominant; this mode corresponds to the first eigenmode of the finger I.

The above conclusions can be used for:

- the design and the optimization of a robotic hand;
- determining the optimal working parameters of such a device.

References

1. Matarić, M.J.: The robotics primer. The MIT Press, Cambridge (2007)
2. Murray, R.M., Li, Z., Sastry, S.: A mathematical introduction to robotic manipulation. CRC Press Inc., Boca Raton (1994)
3. Conrad, J.M., Mills, J.W.: Stiquito for beginners: an introduction to robotics, 1st edn. Wiley-IEEE Computer Society Pr (1992)
4. Masuda, T., Futakawa, A., Koga, E., Inoue, K.: A parametric study of robot arm vibration by simulation analysis. Adv. Robot. **1**(4), 325–342 (1986)
5. Tsetserukou, D., Kawakami, N., Tachi, S.: Vibration damping control of robot arm intended for service application in human environment. In: 2008 8th IEEE-RAS International Conference on Humanoid Robots, pp. 441–446 (2008)
6. Thomsen, D.K., Søe-Knudsen, R., Balling, O., Zhang, X.: Vibration control of industrial robot arms by multi-mode time-varying input shaping. Mech. Mach. Theory **155** (2021)
7. Wang, P.K.C., Wei, J.-D.: Vibrations in a moving flexible robot arm. J. Sound Vib. **116**(1), 149–160 (1987)
8. Abdel-Malek, K., Yang, J., Marler, T., Beck, S., Mathai, A., Zhou, X., Patrik, A., Arora, J.: Towards a new generation of virtual humans. Int. J. Hum. Factors Model. Simul. **1**(1), 2–39 (2006)
9. Săvescu, A.V., Cheze, L., Xuguang, W., Beurier, G., Verriest, J.P.: A 25 degrees of freedom hand geometrical model for better hand attitude simulation. Trans. J. Aerosp. **113**, 270–275, section 1 (2004)
10. Meirovitch, L.: Fundamentals of vibrations. McGraw-Hill, New York (2001)