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Research paper

Automation of an African wooden pestle: pneumatic or hydraulic actuation?

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Abstract

This paper investigates the automation of an African wooden pestle. This device is used in the kitchen to cook traditional African meals. Because pounding food is painful for the human arm and food blenders cause a lack of consistency in the final product, we study the automation of this device by proposing two solutions. The first solution is the closed-loop electro-hydraulic linear actuation. The second solution is the closed-loop electro-pneumatic linear actuation. These two actuators are chosen because they generate a translational force. A particular reference signal is proposed to mimic the pounding process. The numerical simulations executed in the Matlab/ Simulink/ Simscape environment reveal that the hydraulic actuation provides the best results, particularly for products with medium-high mechanical resistance. Future works will present the results obtained with experimental prototypes.

Keywords: *African Pestle; Hydraulic Actuation; Pneumatic Actuation; Proportional Controller; Matlab / Simulink/ Simscape Environment.*

1. Introduction

An African pestle is used in cooking to pound food placed in a mortar. The cook holds the pestle while moving it back and forth in a horizontal direction to pound the product. Sometimes for a mortar, two pestles can be used at the same time. The length of this device can reach 1,5 meters and its mass can reach 4 kg. Its material is mainly hardwood but its color and smell do not permeate into food. Pounded foods include cassava leaves, cassava tubers, boiled plantains, palm nuts, corn etc. The pounding process results in a fine paste or a fine powder. Figure 1 shows an African pestle with its mortar.
The pestle is operated by the arm of a single person. Pounding food is a laborious process for the cook. This requires the pestle to be applied with each stroke at the same point for a long time. In addition, the exerted effort must be consistent enough to grind the food. Modern kitchens use food blenders or mixers to avoid this painful effort. These devices cut food into small pieces using sharp rotating blades (Rooney, Griffiths et al. (2018) and Cullen (2009)). Crushing mills may be also used to crush food (Ibrahim, Omran et al. (2019)). However, replacing the traditional pounding process with a crushing process results in a lack of consistency and a lack of authentic taste in the final product. The authors (Veillet, Tomao et al. 2009) show the existence of chemical changes in foods depending on the crushing systems. Additionally, foods may be contaminated with alloys of Cu, Fe, Al, Ni, Zn, Pb,Co, Cr, and Si (Kalagbor, Fyneface et al. 2017). Chlorinated paraffin may leak from hand blenders (Yuan, Strid et al. 2017) (Strid, Athanassiadis et al. 2014). In their work (Elina, Mika et al. 2023), the authors show the antimicrobial properties of wooden material surfaces. Automating food pounding using a wooden device is becoming a challenge for engineers.

Fig. 1: Medium Size African Pestle and Mortar.

Fluid power systems are well-known for generating translational actuation using cylinders. Examples of using pneumatic power systems include the robot arm actuation (Aliff, Dohta et al. 2014), hand prostheses (Peerdeman, Smit et al. 2012) actuation, and intelligent chair tool (Faudzi, Suzumori et al. 2009). Hydraulic power systems are encountered in applications requiring significant force generation such as heavy-duty robot manipulators (Zhu and Piedboeuf 2005), automotive active suspension (Al Aela, Kenne et al. 2022), machine tools (Sahu, Singh et al. 2020), and aerospace actuators (Zhao, Chen et al. 2020). In the operational part of these systems, power is transmitted according to the Pascal's law (Merritt 1967). The control part is provided via the servo valve providing the interface between the operational part and the control part (Sun, Gao et al. 2023), (Tamburrano, Plummer et al. 2018).
In this paper, we propose to replace the actuation of the human arm with the actuation of fluid power systems. Two solutions are proposed: the hydraulic actuation on the one hand and the pneumatic actuation on the other hand. The proposals are studied and then compared to each other. Thus, the main contributions of this paper can be summarized as follows:

- Hang a wooden pestle on a cylinder;
- Design an African pestle equipped with an electro-hydraulic actuation servo system;
- Design an African pestle equipped with an electro-pneumatic actuation servo system;
- Carry out a comparative study of the two proposals.

The rest of the article is organized as follows: section 2 presents the architecture of the two solutions. Section 3 shows the simulation results. Finally, the conclusion is developed in section 4.

2. Physical modelling

This section describes the architecture of the two solutions proposed to automatically operate the wooden pestle. This step is carried out using the environment and modules of the software Matlab/ Simulink/ Simscape.

2.1. Electro-hydraulic actuation servo system

Figure 2 presents the architecture of the African wooden pestle operated by an electro-hydraulic servo system. The system consists of two parts.

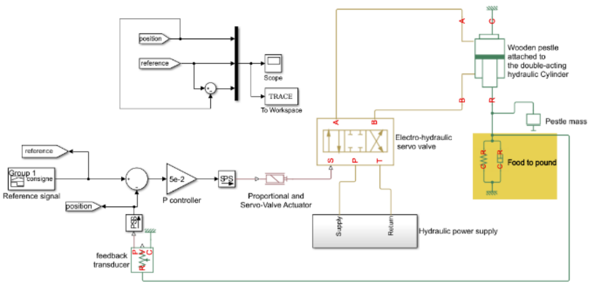

Fig. 2: Electro-Hydraulic African Pestle.

The first part is the operational part including the hydraulic cylinder, the electrohydraulic servo valve and the hydraulic power supply. The hydraulic power supply is responsible for providing the electro hydraulic servo valve with a constant pressure hydraulic oil flow. Based on the electrical input signal, the electro hydraulic servo valve controls the movement of the hydraulic cylinder by allowing, switching or stopping the flow of hydraulic oil flow in its lines. The double acting hydraulic cylinder is responsible for activating the pestle using the pressure difference across its lines due to the load. The mechanical load is represented by the food and the mass of the pestle. The food to be pounded is represented by a viscous damper and a spring.
The second part of the system concerns the components involved in the closed-loop control. The linear position of the pestle is sensed by a transducer and then compared to the reference signal. The reference signal represents the desired position of the pestle during the pounding process. The tracking error existing between the desired and the actual position is sent a simple proportional controller. We use a proportional controller because this paper is focused on the automation possibilities of the African wooden pestle. Future works will investigate other control solutions. The control law signal is sent to the electro-hydraulic servo-valve to control the movement of the hydraulic cylinder.

Figure 3 shows the components included in the hydraulic power supply. Hydraulic oil stored in the atmospheric tank is sent to the system via a fixed displacement pump. The relief valve bypasses excess flow to limit maximum supply pressure.

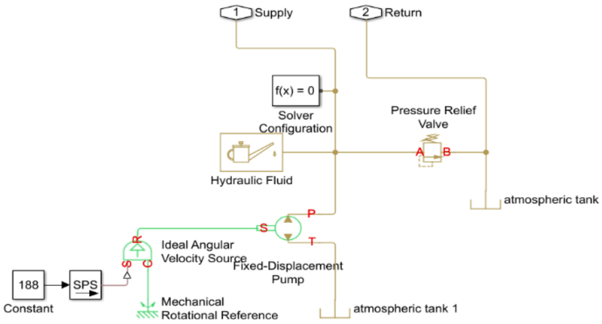

Fig. 3: Hydraulic Power Supply.

2.2. Electro-pneumatic actuation servo system

Figure 4 shows the architecture of an African wooden pestle operated by an electro-pneumatic servo system. The skeleton of the system is the same as that seen previously: a cylinder, a servo valve, a power supply and the components of the closed-loop control. The few differences noted are due to air management accessories.

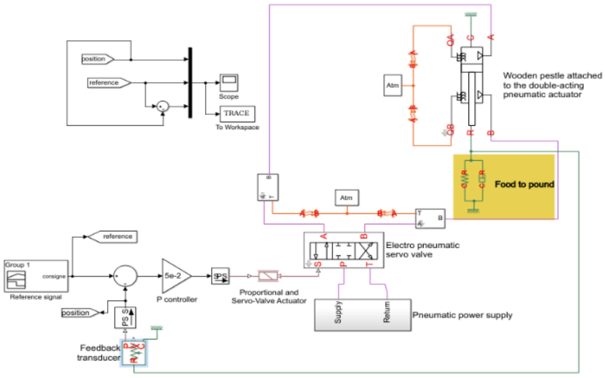

Fig. 4: Electro-Pneumatic African Pestle.

Figure 5 shows the detailed components included in the pneumatic power supply.

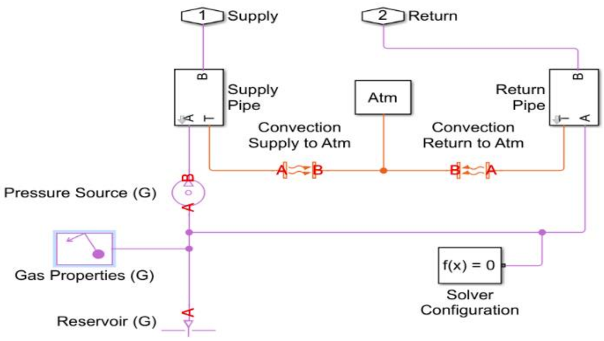

Fig. 5: Pneumatic Power Supply.

3. Numerical results

This section is devoted to the numerical results executed on the Matlab/ Simulink/ Simscape environment. The sampling time to collect data is 0.05 s and the simulation lasts 15 s. The numerical values used in the simulations are recorded in Table 1. We choose the same dimensions for both solutions to better compare performances.

Table 1: Numerical Values Used for the Simulation

Parameter	Value	Unit
Viscous damping coefficient of the food	10	$N/(m.s^{-1})$
Spring stiffness of the food	100	N/m
Mass of the pestle	3	Kg
Piston area of the cylinder	$5x10^{-3}$	m^2
Pestle stroke	0.5	m
Flow discharge coefficient of the servo valve	0.82	
Maximum orifice area of the servo valve	$4x10^{-6}$	m^2
Maximum supply pressure	0.6	MPa
Proportional gain	0.05	

Figure 6 shows the profile of the reference signal used in the simulation. This desired position profile is chosen because it is close to the real position of the pestle orchestrated by the human arm over time.

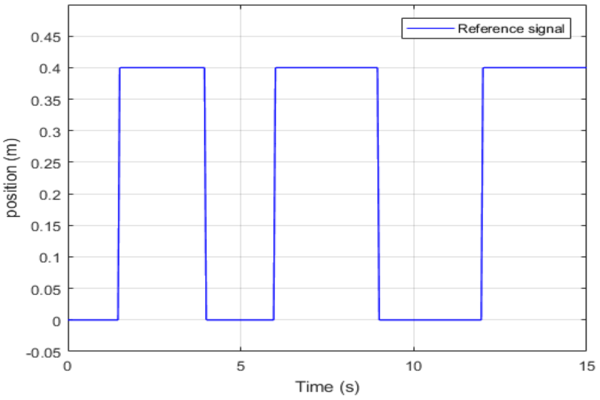

Fig. 6: Desired Position of the Pestle.

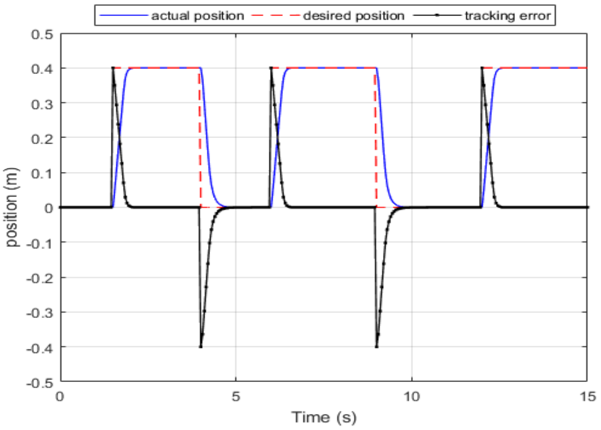

Fig. 7: Response When Using the Hydraulic Actuation.

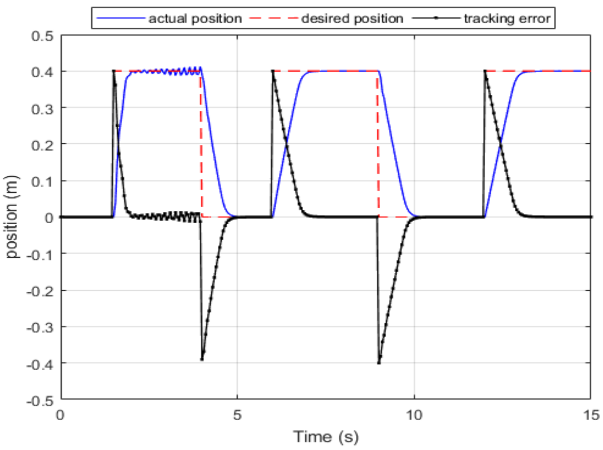

Fig. 8: Response When Using Pneumatic Actuation.

Figure 7 and Figure 8 show the response of the closed-loop system when using hydraulic actuation and pneumatic actuation respectively. The pestle operated with the hydraulic cylinder is more precise and faster than the one operated with the pneumatic cylinder. Hydraulic actuators are known to be much stiffer than their pneumatic counterparts (Salam 2022) (Xiang, Giannaccini et al. 2016). The Authors (Cao, Rakheja et al. 2005) show that improving stiffness results in a rapid response. Fluid bulk modulus is the physical property that indicates the stiffness of the fluid (Gholizadeh, Burton et al. 2011) (Kiani-Oshtorjani, Mikkola et al. 2023). The value of the bulk modulus increases with pressure. However, because of the thermodynamic efficiency of actual compressors, the maximum pressure of the pneumatic system is limited to 1.5 MPa. In contrast, the supply pressure in hydraulic systems can reach 100 MPa. Figure 9 shows the response of the hydraulic system when the supply pressure is increased to 20 MPa. We see that the precision and the speed of the response increase.

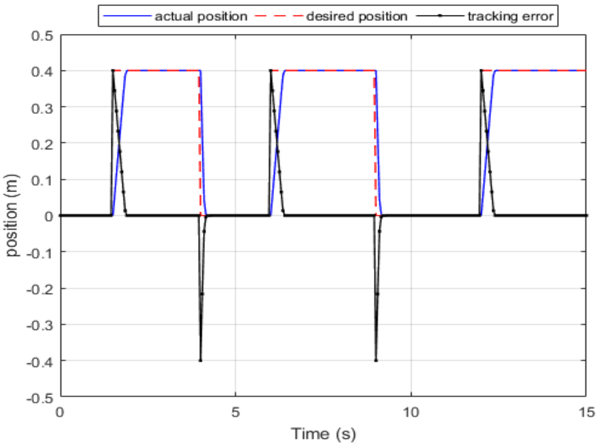

Fig. 9: Response When Using Hydraulic Actuation with an Increased Supply Pressure.

Hydraulic actuation is stiffer, faster and more precise than pneumatic actuation. However, some studies (Xiang, Giannaccini et al. 2016) report that air is safer than hydraulic oil particularly for devices directly involving human health and food. External leaks exists in these fluid power systems (Goharrizi, Sepehri et al. 2011) and can lead to hydraulic contamination.

4. Conclusion

This paper focuses on solutions to automatically operate the African wooden pestle. We proposed a hydraulic linear on the hand and a pneumatic linear actuation on the other hand. The EHSS architecture and the control design are developed using Matlab/ Simulink/ Simscape environment. Preliminary numerical results show that the hydraulic actuation has the best results and additional works need to be done in this direction to commercialize this device. Additional work must be done to secure the food during pounding and prevent contamination from leaks.

References

[1] C. M. Rooney, I. M. Griffiths, C. Brunner, J. Potter, M. Wood-Lee, and C. P. Please, "Dynamics of particle chopping in blenders and food processors," *Journal of Engineering Mathematics,* vol. 112, no. 1, pp. 119-135, 2018/10/01 2018. https://doi.org/10.1007/s10665-018-9968-4.

[2] P. J. Cullen, *Food mixing: Principles and applications*. John Wiley & Sons, 2009. https://doi.org/10.1002/9781444312928

[3] M. Ibrahim, M. Omran, and M. Abd EL-Rhman, "Design and evaluation of crushing hamm.er mill," *MISR Journal of Agricultural Engineering,* vol. 36, no. 1, pp. 1-24, 2019. https://doi.org/10.21608/mjae.2019.94437.

[4] S. Veillet, V. Tomao, I. Bornard, K. Ruiz, and F. Chemat, "Chemical changes in virgin olive oils as a function of crushing systems: Stone mill and hammer crusher," *Comptes Rendus Chimie,* vol. 12, no. 8, pp. 895-904, 2009/08/01/ 2009. https://doi.org/10.1016/j.crci.2009.01.003.

[5] I. Kalagbor, D. Fyneface, U. Korfii, T. Ogaji, and F. Kpoonanyie, "Estimation of the levels of Fe in wheat and maize flour milled using commercial milling machine and a home blender," *Journal of Applied Sciences Environmental Management,* vol. 21, no. 2, pp. 341-344, 2017. https://doi.org/10.4314/jasem.v21i2.15.

[6] B. Yuan, A. Strid, P. O. Darnerud, C. A. de Wit, J. Nyström, and Å. Bergman, "Chlorinated paraffins leaking from hand blenders can lead to significant human exposures," *Environment International,* vol. 109, pp. 73-80, 2017/12/01/ 2017. https://doi.org/10.1016/j.envint.2017.09.014.

[7] A. Strid, I. Athanassiadis, Å. Bergman, and IPEN, "Hand blenders available on the Swedish market may contaminate food with chlorinated paraffins," *J Annex E submission Pamela Miller, Alaska Community Action on Toxics,* 2014.

[8] K. Elina *et al.*, "Touch the wood: Antimicrobial properties of wooden and other solid material surfaces differ between dry and moist contamination in public and laboratory exposure," *Environmental Advances,* vol. 13, p. 100416, 2023/10/01/ 2023. https://doi.org/10.1016/j.envadv.2023.100416.

[9] M. Aliff, S. Dohta, and T. Akagi, "Control and analysis of robot arm using flexible pneumatic cylinder," *Mechanical Engineering Journal,* vol. 1, no. 5, pp. DR0051-DR0051, 2014. https://doi.org/10.1299/mej.2014dr0051.

[10] B. Peerdeman, G. Smit, S. Stramigioli, D. Plettenburg, and S. Misra, "Evaluation of pneumatic cylinder actuators for hand prostheses," in *2012 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob)*, 2012, pp. 1104-1109: IEEE. https://doi.org/10.1109/BioRob.2012.6290807.

[11] A. A. M. Faudzi, K. Suzumori, and S. Wakimoto, "Design and control of new intelligent pneumatic cylinder for intelligent chair tool application," in *2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 2009, pp. 1909-1914: IEEE. https://doi.org/10.1109/AIM.2009.5229768.

[12] W.-H. Zhu and J.-C. Piedboeuf, "Adaptive output force tracking control of hydraulic cylinders with applications to robot manipulators," *Dynamic Systems, Measurement and Control,* vol. 127, no. 2, pp. 206-217, 2005. https://doi.org/10.1115/1.1898237.

[13] A. M. Al Aela, J.-P. Kenne, and H. Angue Mintsa, "Adaptive neural network and nonlinear electrohydraulic active suspension control system," *Journal of Vibration and Control,* vol. 28, no. 3-4, pp. 243-259, 2022. https://doi.org/10.1177/1077546320975979.

[14] G. N. Sahu, S. Singh, A. Singh, and M. Law, "Static and dynamic characterization and control of a high-performance electro-hydraulic actuator," in *Actuators*, 2020, vol. 9, no. 2, p. 46: MDPI. https://doi.org/10.3390/act9020046.

[15] S. Zhao *et al.*, "A Generalized Control Model and Its Digital Algorithm for Aerospace Electrohydraulic Actuators," in *Proceedings*, 2020, vol. 64, no. 1, p. 31: MDPI. https://doi.org/10.3390/IeCAT2020-08500.

[16] H. E. Merritt, *Hydraulic Control Systems*. John Wiley & Sons Inc, 1967.

[17] H. Sun, L. Gao, Z. Zhao, and B. Li, "Adaptive super-twisting fast nonsingular terminal sliding mode control with ESO for high-pressure electro-pneumatic servo valve," *Control Engineering Practice,* vol. 134, p. 105483, 2023. https://doi.org/10.1016/j.conengprac.2023.105483.

[18] P. Tamburrano, A. R. Plummer, E. Distaso, and R. Amirante, "A review of electro-hydraulic servovalve research and development," *International Journal of Fluid Power,* pp. 1-23, 2018. https://doi.org/10.1080/14399776.2018.1537456.

[19] M. A. Salam, "Hydraulic cylinders," in *Fundamentals of Pneumatics and Hydraulics*: Springer, 2022, pp. 257-286. https://doi.org/10.1007/978-981-19-0855-2_7.

[20] C. Xiang, M. E. Giannaccini, T. Theodoridis, L. Hao, S. Nefti-Meziani, and S. Davis, "Variable stiffness Mckibben muscles with hydraulic and pneumatic operating modes," *Advanced Robotics,* vol. 30, no. 13, pp. 889-899, 2016. https://doi.org/10.1080/01691864.2016.1154801.

[21] D. Cao, S. Rakheja, and C.-Y. Su, "Comparison of roll properties of hydraulically and pneumatically interconnected suspensions for heavy vehicles," SAE Technical Paper0148-7191, 2005. https://doi.org/10.4271/2005-01-3593.

[22] H. Gholizadeh, R. Burton, and G. Schoenau, "Fluid bulk modulus: a literature survey," *International Journal of Fluid Power,* vol. 12, no. 3, pp. 5-15, 2011. https://doi.org/10.1080/14399776.2011.10781033.
[23] M. Kiani-Oshtorjani, A. Mikkola, and P. Jalali, "Novel bulk modulus model to estimate stiffness in fluid power systems," *Mechatronics,* vol. 92, p. 102987, 2023. https://doi.org/10.1016/j.mechatronics.2023.102987.
[24] A. Y. Goharrizi, N. Sepehri, and Y. Wu, "A wavelet-based approach for online external leakage diagnosis and isolation from internal leakage in hydraulic actuators," *International journal of fluid power,* vol. 12, no. 2, pp. 37-47, 2011. https://doi.org/10.1080/14399776.2011.10781029.