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LQR control of multi-DoF absorber for planar robots

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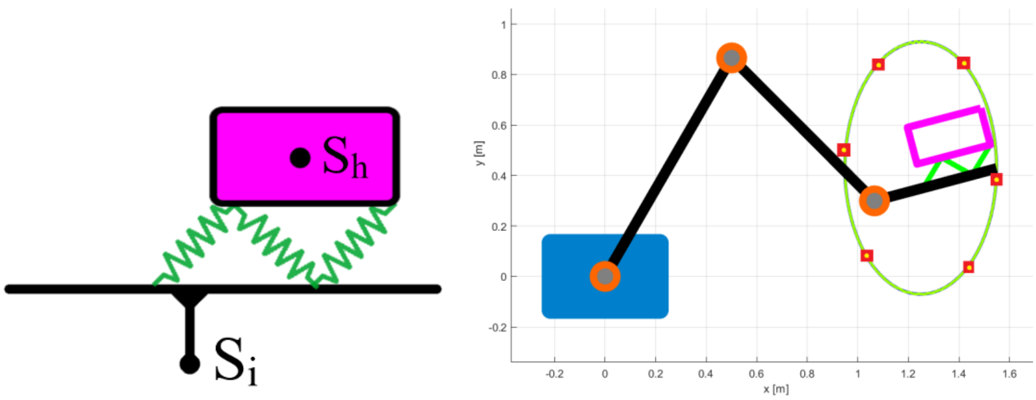
Vibration suppression takes place in many applications, including robotics. The serial robots are one of the examples of robots, which can serve large workspace, but also have large mass/stiffness ratio, which leads to low accuracy of the end-effector during high dynamic operations, e.g. drilling [2]. In such cases, serial robot needs to be more precise, even when externally excited by the drilling harmonic force or other disturbances. Attaching an additional absorber mass to the primary structure is one of the approaches to suppress vibrations among many others and will be discussed in this paper.

Firstly, the single-mass multi-degrees-of-freedom absorber is used to manage the task rather than many single-axis absorbers combined. It has the advantage of smaller mass with same effect in multiple axes, which leads to lower spatial and power requirements. Secondly, an active approach is chosen to cover more configurations of primary system. Passive tuning is still important as a base design, since it is supposed to handle the major forces, leaving the active part of the solution to do the rest with smallest possible power requirements. There are various algorithms (mostly centralized) that can be used to drive absorber's actuators, such as PID regulation, H-inf, LQR [3], Delayed resonator [1], etc.

In this paper, LQR algorithm is considered as initial control design, which controls three voice-coil actuators placed perpendicularly to each other (Fig.1a) along with springs of the planar absorber. This attached actuated spring-single-mass multi-DoF system is used to suppress vibrations of flexible planar simulated serial robot (Fig. 1b) in various positions of workspace. Such a system should be able to work while following the trajectory of the robot, along which the properties of the primary structure varies significantly. The LQR algorithm always needs to be aware of the current position of the robot and use appropriate linearized model of the structure. There are three basic questions to be answered.

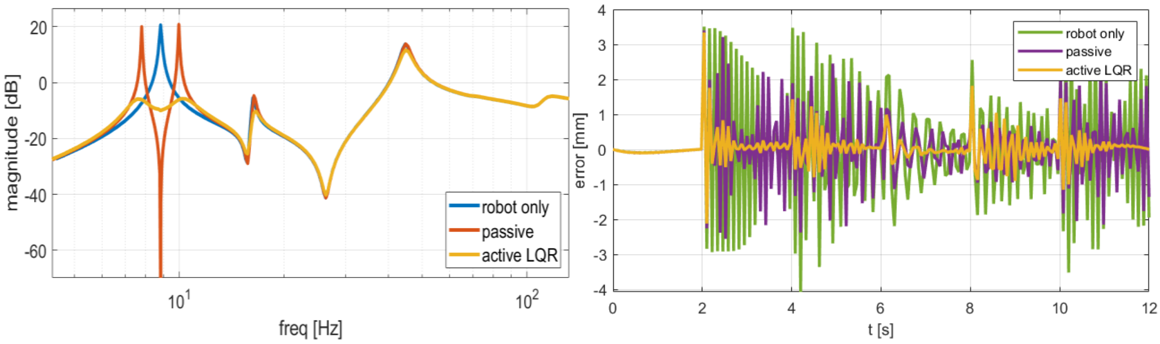


a) Planar absorber attached to arm b) Planar robot with trajectory

Fig. 1. Planar absorber design and its attachment to planar serial robot following specific trajectory

Mainly, linearized models need to be known in advance. A grid of ABCD matrices has to exist through workspace of the system with sufficient density (red squares in Fig. 1b), so there are small enough differences from the real state in every position. Gain scheduling is then applied to combine results from neighbors linearized model. After that, linearized models must be precise enough to be able to observe the whole system. Observation could be performed using any built-in sensors of the robot and few extra attached sensors, that has to be robust and relative (e.g. absolute position measurement can be challenging in industrial environment), so absorber's actuator's encoders, conveniently located accelerometers or velocity measurement through geophones would be first to join the observation. Finally, an efficient cost function of the LQR algorithm needs to be designed, which aims to as low vibrations of the end-effector as possible. That can be achieved through velocity or acceleration amplitudes of the observed end-effector, since position observation is more prone to errors when sliding between grid points of known linearized models.

Fig. 2a compares amplitude characteristics of the robot itself to robot with attached passive absorber (tuned to first eigenfrequency of the robot) and to active absorber controlled by LQR algorithm (using full state feedback so far). Observation of the primary system using unperfect linearized models makes the results little bit hazier and is in process of evaluation. Fig. 2b then compares same cases, only in time domain, when external force impulse acts on the end-effector every 2 seconds through whole 12 seconds trajectory shown in Fig. 1b.



a) Amplitude characteristics b) Time impulse responses

Fig. 2. Responses of the robot's end-effector with or without passive/active absorber

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References

[1] Olgac, N., Elmali, H., Hosek, M., Renzulli, M., Active vibration control of distributed systems using delayed resonator with acceleration feedback, Journal of Dynamic Systems, measurement, and control 119 (3) (1997) 380-389.

[2] Olsson, T., Haage, M., Kihlman H., et al., Cost-efficient drilling using industrial robots with high-bandwidth force feedback, Robotics and Computer-Integrating Manufacturing 26 (1) (2010) 24-38.

[3] Šika, Z., Kraus, K., Beneš, P., Vyhlídal, T., Valášek, M., Active multidimensional vibration absorbers for light robots, Proceedings of the 5th Joint International Conference on Multibody System Dynamics, Lisbon, 2018, pp. 1-12.