Simulation and Control of a Flexible Robotic Arm in Space

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Abstract

As the LEO and GEO orbits become more accessible, they become crowded with satellites and debris. Consequently, the need for debris collection increases [1]. Sending a chaser to these orbits equipped with a robotic arm, would be an elegant solution to this problem. An example of a robotic arm in space can be seen in Fig. (1). Therefore, this project focused on the simulation and control of a flexible robotic arm in space.

Fig. (1): Robotic arm in space.

Background

The medium used for this simulation was Simscape (a MATLAB software package). The concept of a flexible robotic arm was chosen, inspired by continuum arms, more specifically, a tensor arm [2]. This choice was made so that the agility of the arm is increased, and a wider variety of tasks can be realised. Controlling vibrations is quite difficult, especially if there are uncooperative targets or/and unknown parameters. However, this is exactly why wave-based control (WBC) is the perfect choice for this application; along with the fact that no actuator sensing is needed [3]. It is a robust method, and it provides a fairly fast response [3]. This simulation takes place in a 2D plane (X-Y plane).

Simscape

Simscape was chosen, as it had not been used before for this application. The flexible robotic arm is composed of 5 links and an end effector, all connected by torsional springs and dampers. The material used for the links and end effector is aluminium. A brushless DC motor was chosen to provide the input. The animation of this system can be seen in Fig. (2).

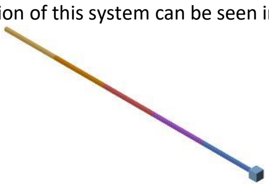


Fig. (2): Animation of system.

Wave-Based Control (WBC)

WBC works by sending a mechanical wave to the flexible system, while simultaneously absorbing the returning wave (either fully or partially) [4]. Lumped systems use "wave transfer functions" (WTFs) to model incoming and outward-going waves [4]. Each WTF can be assumed to be G, a second-order system, as the important dynamics and steady-state features are simulated accurately [4]. This is represented in Fig. (3).

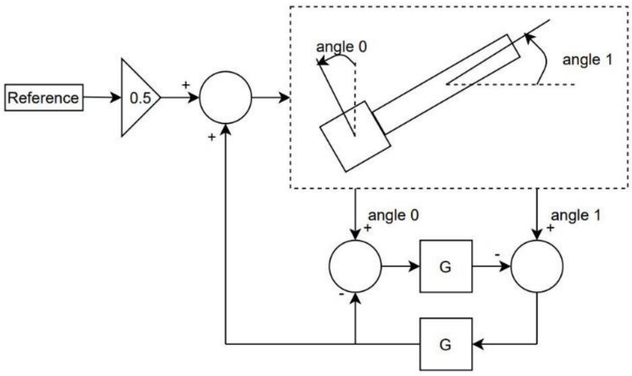


Fig. (3): WBC diagram.

Where: $G = \frac{\omega^2}{s+s\omega+\omega^2}$, $\omega = \left(\sqrt{\left(\frac{k1}{m1}\right)}\right) \times 0.1$, k1=spring stiffness relating to the first link, m1=mass of the first link.

Results, Discussion & Future Work

The results obtained for the first link angle, with and without the WBC, can be found in Fig. (4). The results obtained for the end effector angle, with and without the WBC, can be found in Fig. (5). As can be seen, the overall vibration of the system is reduced, as desired.

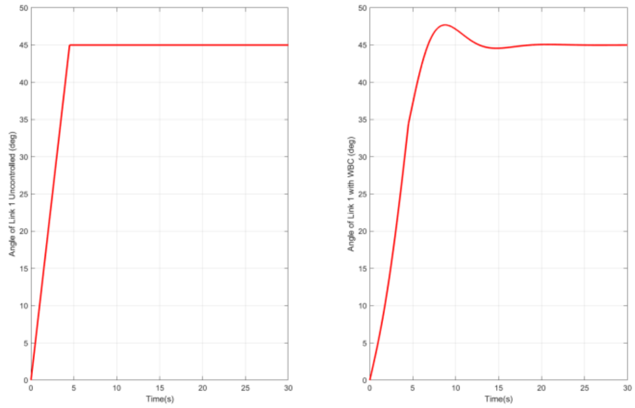


Fig. (4): Responses of angle of the first link.

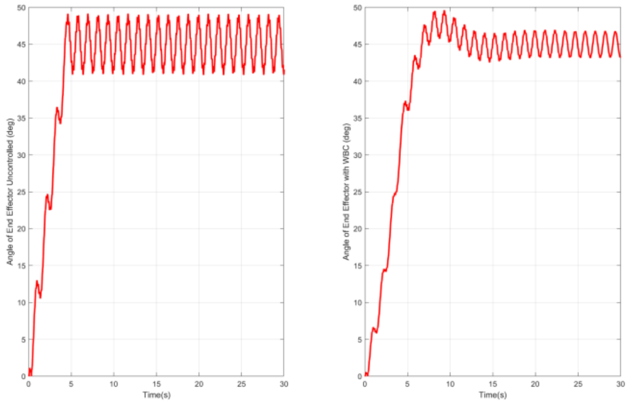
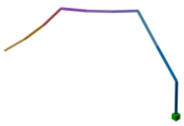


Fig. (5): Responses of end effector angle.

In the future, implementing WBC on every 3 links for a 9-link-long arm, could yield promising results, as seen in Figs. (7). This was not studied in this project as there were time constraints. Furthermore, interesting work could also be done on the end effector, as can be observed in Fig. (8).



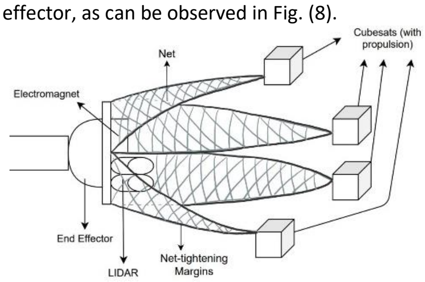


Fig. (7): 9-link-arm. *Fig. (8): End-effector future work.*

Furthermore, machine learning could have also been used to tune the control parameter ω. Besides machine learning, there are other approaches that could have been used to improve the response, such as filters.

Conclusion

Simscape is not the best simulation medium, as it lacks the detail necessary to observe the full range of benefits of WBC. Better results would be obtained by using mathematical equations of motion in MATLAB and Simulink. WBC is a superior control method for supressing vibrations, as it remains effective for a wide range of parameters and disturbances.

References

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[3] Meng, D., Liu, H., Li, Y. et al. *Vibration suppression of a large flexible spacecraft for on-orbit operation.*

[4] O'Connor, W.J., Ramos de la Flor, F., McKeown, D.J. et al. *Wave-based control of non-linear flexible mechanical systems.*

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