INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES RENNES

UNIVERSITÉ DE RENNES 1

Research Grants for PhD students from the China Scholarship Council

DESIGN OF GRAVITY-COMPENSATION ADAPTIVE SYSTEMS FOR ROBOT MANIPULATORS

The actuator power required to resist joint torque caused by the weight of robot links can be a significant problem. Gravity compensation is a well-known technique in robot design to achieve equilibrium throughout the range of motion and as a result to reduce the loads on the actuator. Thus, gravity compensation is beneficial, by which a robotic system can be operated with relatively small actuators generating less torque. Therefore, it is desirable and commonly implemented in many situations. For gravity compensation in robot mechanisms, different approaches and solutions have been developed and documented. The balancing schemes for robotic systems can be systematized by taking into account the nature of the compensation force: *i)* With counterweights: this is a classical approach which consists in adding counterweights in order to keep the total centre of mass of moving links stationary. *ii)* With spring: the approaches developed in this group are based on the use of either zero-free length springs or non zero-free length springs. *iii)* With a complementary actuator which can be a pneumatic or hydraulic cylinder, electromagnetic device, etc. In this case, a pneumatic or hydraulic cylinder is connected with some manipulator links or directly with the moving platform. There are also some approaches based on special counterweights, which are fluid reservoirs. Continuous gravity compensation is achieved by the pumping of fluid from the first reservoir-counterweight to the second.

The main drawbacks of the mentioned solutions when applied to robotics is that they ensure the gravity balancing of the robot for a given gravity load. However, when this load is varying (for example, during a palletizing task), they cannot ensure the cancellation of the gravity effects due to change of the payload.

Within the framework of this PhD thesis, a novel gravity compensation system will be developed. The objective of this work is to design a balancing solution capable of compensating for the gravitational effects of a manipulated payload whose mass may vary during operation. In many robotic or mechanical manipulation systems, changes in payload lead to variations in gravitational torque, which can negatively affect system performance, stability, and energy consumption if not properly compensated.

Most existing gravity balancing techniques are designed to compensate for gravitational effects associated with variable loads. However, these solutions often rely on active mechanisms or continuous energy input to adapt the system to different payloads. As a result, the adjustment process may require a significant amount of energy, reducing the overall efficiency of the system.

The proposed gravity compensation system aims to address this limitation by focusing on energy efficiency. In particular, the system should be capable of adapting to changes in the manipulated payload while requiring only minimal energy for adjustment. The goal is therefore to develop an innovative balancing mechanism that maintains effective gravity compensation across a range of payloads while minimizing the energy required for reconfiguration. Such a solution would contribute to improving the overall efficiency, sustainability, and practicality of gravity-balanced mechanical and robotic systems.

Simulations of the mechanical systems with ADAMS will have to be carried out in order to confirm the effectiveness of the proposed approach. The proposed design concept will be validated via demonstrators.

Related recent publications by members of research team:

- V. Arakelian, S. Briot. Balancing of linkages and robot manipulators. Advanced methods with illustrative examples, Springer, 2015, 291p. (ISBN: 978-3-319-12489-6).
- Gravity compensation in robotics (Ed. V. Arakelian), Springer, 2022 (ISBN 9783030957490)
- Y. Lu, Y. Aoustin, V. Arakelian. Mechatronic design of dynamically decoupled manipulators based on the control performance improvement. Robotica, 41(2), pp. 609-631 (2023).
- Y. Zhang, V. Arakelian. Design, Optimization and control of a cable-driven robotic suit for load carriage. «Gravity compensation in robotics», Springer, pp. 125-146 (2022).
- V. Arakelian. Design of Torque-compensated mechanical systems with two connected identical slider-crank mechanisms. ASME Journal of Mechanisms and Robotics, 14(2), 024503 (2022).
- S. Ghazaryan, M. Harutyunyan, Y. Sargsyan, V. Arakelian. Design of statically balanced assistive devices. "Gravity compensation in robotics", Springer, pp. 165-192 (2022).
- J. Geng, V. Arakelian, D. Chablat, Ph. Lemoine. Balancing of the Orthoglide taking into account its varying payload. J. Robotics, 10(1), 30 (2021).
- V. Arakelian, Y. Zhang. An improved design of gravity compensators based on the inverted slider-crank mechanism. ASME Journal of Mechanisms and Robotics, Vol. 11, 034501 (2019).
- Y. Zhang, V. Arakelian, B. Véron, D. Chablat. Key features of the coupled hand-operated balanced manipulator (HOBM) and lightweight robot (LWR). «Advances in Mechanism and Machine Science», Springer, pp. 2289-2298 (2019).
- S. Briot, V. Arakelyan. Load - Balancing Device for Articulated Arm, Associated Load - Handling Apparatus and Method. Patent No. : US 10,293,495 B2, Date of Patent: May 21, 2019.
- V. Arakelian. Gravity compensation in robotics. Proceedings of the 7th International Conference on Trends in Agricultural Engineering, 17-20 September, 2019, Prague, Czech Republic, pp. 45-50 (2019).
- V. Arakelian. Mobility of Mechanisms and Robot Manipulators: A Training Manual with Illustrative Examples. 2025, 171p.
- V. Arakelian, Y. Zhang, J.P. Le Baron. Linkage design for gravity balancing by means of non-zero length springs. "Robot design, dynamics and control", Springer, pp.163-171 (2018).
- V. Arakelian, J. Xu and J.-P. Le Baron. Mechatronic design of adjustable serial manipulators with decoupled dynamics taking into account the changing payload. Journal of Engineering Design, 27(11), pp. 768-784 (2016).

Contact:

Prof. Vigen ARAKELYAN
Mail : vigen.arakelyan@insa-rennes.fr

Address:

Department of Mechanical and Control Systems Engineering
I.N.S.A. Rennes, 20 av. des Buttes de Coësmes
CS 70839, F-35708 Rennes
France