Research Grants for PhD Students from the China Scholarship Council

Title**: Vibration synthesis, elasto-dynamic modeling, identification and control of parallel robot.**

Laboratory: LGCGM, EA-3913, Calibration and Control of Robotic Systems team.

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State-of-art:

The parallel robots are now gradually being implemented to carry out various applications in various fields such as medical, flight simulation and high-speed machining. To make the accuracy of these machines compatible with these applications, it is necessary to model, identify and compensate all the effects that degrade this precision. These effects may be caused by (the references for each topic represent the work already carried out by our research team):

- Errors in the geometry tolerances of the structure associated with machining and assembly errors of the various constituting bodies,
  - ECORCHARD G., NEUGEBAUER R., MAURINE P., "Elasto-geometrical modeling and calibration of redundantly actuated PKMs, Mechanism and Machine Theory", Volume 45, Issue 5, May 2010, Pages 795-810.
- Elastic deformations of their structure under the effect of the weight of the load on the one hand and their own elements on the other hand,
  - DEBLAISE D., « Contribution to the elasto-geometrical modelling and calibration of parallel manipulators ». PhD Thesis. Supervisor Professor E. RAGNEAU – co-supervisor Assistant Professor P. Maurine.
  - MARIE S., COURTEILLE E, MAURINE P., "Elasto-geometrical modeling and calibration of robot manipulators: Application to machining and forming applications". Mechanism and Machine Theory, 69, 13-43, 2013.
- Structural vibrations (bodies and joints) as a result of inertia forces applied on their parts and on the load during high-speed trajectory or at the interaction between own modes of the structure and dynamic excitation at the tool interface,
  - ROGNANT M., « A systematic procedure for the elasto-dynamic modelling and identification of robots manipulators", IEEE Transactions on Robotics and Automation, 2010.
  - COURTEILLE E., DEBLAISE D., MAURINE P., "Design Optimization of a Delta-Like Parallel Robot through Global Stiffness Performance Evaluation", 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, October 11-15, 2009, Hyatt Regency St. Louis Riverfront, St. Louis, USA
- Errors due to the lack of knowledge of dynamic parameters of the mechanical structure, which are implemented in control laws,
  - GUEGAN S., KHALIL W., LEMOINE, "Identification of the Dynamic Parameters of the Orthoglide", in Proc. IEEE Int. Conf. Robot. Autom., Taipei, Taiwan, 2003.

- GUEGAN S., KHALIL W., "Inverse and Direct Dynamic Modeling of Gough-Stewart Robots", IEEE Transaction on Robotics and automation, 20-4, pp. 754-762, 2004.
- ARAKELIAN V., GUEGAN S., BRIOT S. "Static and Dynamic Analysis of the Paminsa ", in Proc. ASME IDETC/CIE, Long Beach, California, September 2005.
- BARADAT C., ARAKELIAN V., BRIOT S. , GUEGAN S., "Static and Dynamic Analysis of the Paminsa ", Journal of Mechanical Design, 130-7, 2008.

The work completed on this set of topics within the Calibration and Control of Robotic Systems team showed the relevance of an elasto-geometrical and elasto-dynamic modeling and its calibration. The analytical models thus defined makes it possible to calculate the elasto-static deformation of the structure, under the effect of the weight of the load on the one hand, and of the weight of the elements of the structure on the other hand. It let moreover calculate in real-time the modal cartography and vibratory deformations of parallel structures due to the effects of inertia forces applied on their parts and on the load in high-speed operating conditions, or machining cycle.

Next work is a further development of the vibration synthesis on parallel manipulators to compensate errors in positioning of the tool. There are many factors including the mass content of the actuators, the bearing flexibilities, play and hysteresis problems at their joint components that contribute significantly to the overall dynamic structural behaviour of the system. The elasto-dynamic model accuracy should be increased to predict the effect of these factors on the positioning deformations of the tool.

The elasto-dynamic model will not provide a true representation of the mechanism unless the structural properties (i.e. mass, stiffness and damping) of the mechanism are sufficiently identified. An experimental procedure should be developed to identify all significant contributing parameters. For that, the methods developed for rigid structure based on the inverse dynamic model need to be extended. The identification of the dynamic parameters is based on the fact that the inverse dynamic model of parallel robots can be expressed as a linear relation in the dynamic parameters. This model allows the use of the least squares method to solve the estimate. Other methods should also be investigated.

In a first step, we will focus on the bearing flexibilities of the passive joints. In literature, the stiffness of the robot's joints is classically described using elastic elements with their associated stiffness matrix. For sake of simplicity, the associated stiffness matrix is constant and diagonal, described only by the axial and radial translational stiffnesses and the axial and radial rotational stiffnesses. The idea here is the calculation of the stiffness matrix of angular contact ball bearings joint to obtain a more accurate formulation by using the analytical approach developed in:

- HERNOT, X., SARTOR, M., et GUILLOT, J. Calculation of the stiffness matrix of angular contact ball bearings by using the analytical approach. *Journal of mechanical design*, 2000, vol. 122, no 1, p. 83-90.

The validity of all the methods and the identified parameters will be verified on the 3RRR parallel robot available at the laboratory, developed internally and whose characteristics are well known.

Throughout this work, the study of the sensitivity of the parameters, their influences and their identifiability will be important in order to keep only the significant contributing parameters to have simple reduced analytical models, which can be implemented in a real time control system.

In order to observe the improvements obtained with the elasto-dynamic model, this last will be implemented in new control laws and compare with classical computed torque control scheme.

Study required:

1. Literature review on elastic and dynamic identification of parallel robots. Will be discussed during this literature review, aspects of modelling, identification and compensation of all vibratory effects degrading the positioning accuracy. First, the stiffness of the angular ball bearing joints will be studied.
2. Increase accuracy of the elasto-static and elasto-dynamic models of the planar 3RRR robot obtained through the ADAMS Software.
3. Experimental validation of the methods on the planar 3RRR parallel robot available at the laboratory: elasto-geometric calibration, dynamic calibration, verification of the elasto-dynamic modeling by identifying the modal cartography of the structures by experimental modal analysis.
4. Study the extension of the computed torque control scheme using the elasto-dynamic model and the estimated values of the significant contributing parameters.

Keywords:

Parallel kinematic manipulator, elasto-dynamical modeling, stiffness, ball-bearing, modal analysis, identification, dynamic control.

Skills:

The candidate must have skills in:
- Modeling, analysis, simulation and optimization of mechatronic systems ;
- Robotics ;
- Modeling and control of robots (MATLAB, CATIA, ADAMS)

Skills in signal processing, vibrations analysis and experimental modal analysis will be appreciated.