Minimum Energy Control of Redundant Manipulators using Bi-level Optimization

Yoram Halevi

Faculty of Mechanical Engineering,
Technion – Israel Institute of Technology

ABSTRACT

Redundant manipulators are mechanical systems with more degrees of freedom than required for their task. As a motivating example that will be used throughout the talk consider an x-y table that carries a smaller x-y on which the end-effector is mounted. The redundancy can be used for enhancing some aspects of the performance, e.g. mission time, sensitivity or accuracy. In this work we consider energy consumption minimization.
The talk will summarize the main results of the research that the speaker, together with students and colleagues, is involved in for a number of years. Its first phase was carried out for the case where the end-effector path is given and the problem was the optimal distribution between the participating dof's. It was formulated as an optimal control problem where the constraints, e.g. maximum stroke and control saturation, were dealt with by means of quadratic penalty functions. The solution was accomplished via a series of projections which separate the states and inputs into those maintaining the perfect tracking and those which are free for optimization. Then a lower order optimal control problem was formulated and solved. The solution showed considerable reduction in the cost but still had some limitations. First, full determination of the motion, even in subtasks of lesser importance, is unnecessarily restrictive. Then there are the well-known computational difficulties when attempting to solve optimal control problems with long duration. Finally, as a result of using penalty functions, the solution was sub-optimal.

The current approach which will be the main focus of the talk decomposes each task into several sub-tasks, having two possible types. Tracking sub-tasks (TST) which represent the 'useful' parts where the end-effector has to follow a given path and motion sub-tasks (MST) that have only to bring the end-effector to the right place. This decomposition allows the formulation of a bi-level optimization problem. The higher level is a discrete decision making scheme which determines the path, while the lower level finds the optimal input among those that generate that path. As a result of this formulation, decision making can be optimized by Genetic Algorithm and the lower level for each task by classical optimal control methods. Both the optimal path and optimal control are solved simultaneously. As a byproduct of the approach, the effect of the penalty functions becomes much smaller since the higher level cost is the exact energy consumption.

BIO:

Yoram Halevi is the James H. (Jimmy) Belfer Professor in the Faculty of Mechanical Engineering at the Technion, Israel Institute of Technology. He received his B.Sc., M.Sc. and D.Sc. degrees in Mechanical Engineering from the Technion in 1974, 1981 and 1985 respectively. He held visiting positions at Penn State, Ohio State and Virginia Tech in the US and in CNR-ITIA in Milan, Italy as well as short term visits to other universities and research institutes. His public activities include serving as President of Israel Association of Automatic Control (2000-2004), Chair of ASME Europe conference committee (2009-2011), Dean of the Division of Continuing Education and External Studies (2013-2014) and Dean of the Faculty of Mechanical Engineering, Technion (2014-2018). His current research interests are in control of flexible structures, optimal control of redundant actuation systems, model order reduction and model updating. Yoram Halevi is a Fellow of ASME.