Implementation of Control in Redundant Parallel Robotic Structures

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Nowadays, the future development of new industrial robots (parts of machine tools and manipulators) requires also improvement and development of their control. In essence, it means a replacement of existing conventional control approaches (e.g. NC systems, PID/PSD control structures) by new approaches, which enable as much as possible to use available information on properties and behavior of given plant.

Conventional approaches provide control of industrial robots only from view of drives as separate units, but they do not solve control from view of whole robotic system. On the other hand, modern control approaches take in to account dynamics and kinematic relations of given machine. In this way, they design energetically useful control actions. These approaches allow increasing of productivity by use of saved energy.

Dynamics and kinematic relations (available information on given robotic plant) can be represented by different mathematical models, often in a form of differential equations. They are obtained according to theory of mechanics (e.g. principle of virtual works, composition of equations of motion by Lagrange's equations, etc.). The equations can be formulated as input-output models or state-space models. For real use, the models are usually transformed to discrete form. Discretization with appropriate sampling period provides naturally computation time for model composition and design of control actions. When the models are nonlinear, then the part of model composition contains also some kind of linearization procedure.

Approaches, using certain mathematical model, are generally called model-based control approaches. There exist a lot of types in control theory. Mostly, they differ by length of prediction to future during computation of control actions. Suitable example of model-based approaches is multi-step Predictive control, applicable in new developed industrial robots.

Basic questions of robot control follow partly from their constructions and partly from technological requirements – expected behavior. In the branch of parallel structures, especially redundantly actuated, fundamental control task is, how to provide optimal cooperation of all drives interconnected by robot arms through movable platform (chuck, gripper).

Predictive control uses mathematical model (description of kinematic relations and dynamics of robot) and quadratic optimality cost function to design of control actions. This approach combines feedback ~ feedforward parts. The model represents specific prior information, which is used for forming the dominant part of control actions.

Attached feedback from measurable robot outputs compensates model inaccuracies and certain bounded disturbance. It composes remaining part of designed actions.

According to marking “predictive”, this control is based on prediction, which is computed by means of mathematical model. Prediction is realized only within certain horizon of prediction. In case of speedily changed systems, the horizon represents only several multiples of sampling period.

Designed actions correspond to current requirements to motion of movable platform. This way, the requirements to input energy are led towards optimal energy consumption. Moreover, among others, Predictive control can be use for trajectory planning of possible motion among points of robot workspace, solution of backlash problem and solution of steady state error in cases of accurate positioning.

In comparison with usual control approaches based on PID/PSD control or other possible high-level model-based controls (Inverse Dynamics Control, Sliding Mode Control), Predictive control offers simple setting of parameters. It generally represents only tuning of two main parameters - horizon of the prediction and input penalization. Their choice is not difficult. Horizon of prediction relates to time constant of controlled system and selected sampling. The magnitude of input penalization (usually normalized so that control error penalization is equaled one), determines stiffness of response of controller and thus even tracking quality of desired trajectory during robot motion. It is selected in comparison to potential of drives.

Presented control approach was successfully tested on two types of constructions based on parallel principle. The constructions represent both horizontal and vertical configurations, which differ by levels of potential energy. It was shown that Predictive control is able to achieve better results than simple realization of PSD controller. For all practical purposes, for industrial use, Predictive control represents promising way to future in spite of more demanding requirements to its preparation (composition of mathematical model; adjustment of predictive algorithm for given real plant – configuration; more precise trajectory planning – smoothing problems).

References:

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