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Linear Parameter-Varying Modeling for Gain-Scheduling Robust Control Synthesis of Flexible Joint Industrial Robot

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Abstract

Industrial robot features a multivariable, nonlinear and coupled dynamics property, which is always the inevitable topic for control engineer to face during the design of motion controller to achieve desired performance. In the past half century, motion control of industrial robot has gone through a sustainable development from no model involved to model based, from rigid body model to flexible joint model, and even more delicate models of higher order with flexibility in non-drive-train components are also introduced lately. Involvement of gradually refined dynamic model into control design, as well as manipulator design, has become a dominating approach for robot manufacturer to pursue competitive performance and keep technological leadership. Focusing on dynamic modeling, this paper introduces the formulation and approximation of a novel linear parameter-varying (LPV) model for the three main axes of typical six degrees-of-freedom (DOF) elbow type robot, which converts the strong nonlinear system into a quasi linear one globally dependent on certain scheduling parameters. This modeling method, as the prerequisite step for gain-scheduling robust control synthesis, paves the way for further step towards the implementation of LPV gain-scheduling modeling and control techniques for full robot in the next step.

Keywords: industrial robot; flexible joint; LPV modeling; gain scheduling; robust control.

1. Introduction

Modeling techniques of industrial robots are constantly developed and corresponding dynamic models are increasingly refined to be closer to the actual cases. As a consequence, on one hand, controller designed with advanced model can exert the maximum performance out of the robot with prior

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knowledge of robot's various limits and vibration modes. But on the other hand, a less conservative controller will become more sensitive and susceptible to potential deviations between ideal and realistic cases, such as individual physical differences between robots, extra flexibilities serially existing in foundation or tool, definition error of payload or armload and disturbances from high process force. All of these non-ideal factors may lead to unexpected degradation of performance and thus bring forward a higher requirement of in-depth understanding and proper operation on engineering personnel on site. But even if models are becoming more and more accurate, it can never fully represent the overall properties of real system with existence of various inevitable inherent nonlinearities, such as hysteresis effect [1] and Stribeck effect [2][3] in gearboxes, which are hard to be modeled and incorporated into control design.

From the perspective of industrial practices, only one or several prototypes are usually identified and verified against ideal nominal model at the initial development stage of a new robot and then a common set of modeling parameters will be deployed for each robot individuals to be produced. As a consequence, robot individuals at following serial production could be probably subject to potential property deviation imported from different batches of raw materials in spite of strict execution of incoming quality check. So this will cause accurate prior knowledge of system not applicable to specific unit and the inconsistency between them will lead to incapability of desired performance. Even if time-consuming parametric identification process is especially conducted for specific robot one by one in production, it is still not an advisable solution since robot, as a nonlinear time-variant system, will also behave differently with operation hours going on and electromechanical components worn out at customer site. So utilization of high order complex models will be a double-edged sword. On one hand, intensive knowledge of system will undoubtedly help to dig out the potential of a robot, but on the other hand, accurate model, if blind to possible parametric perturbation in practice, will not express the actual system properly and even undermine its normal operation oppositely. So how much is the suitable level to which we should refine the dynamic description of system and how robust the system behaves to tolerate the model uncertainty will be a trade-off issue.

During the modeling of industrial robot, it is impossible to take all of the above uncertainties into consideration. Due to the missing information by unmodeled dynamics, robot is actually blind to the existing nonlinear factors and nonideal external conditions, which will degrade its expected stability and performance designed under ideal circumstances. And even if all of necessary dynamics are covered by advanced modeling methods, parametric uncertainty, including deviation or drifting of modeled parameters, can always be unavoidable. Such situation restricts further development of the classical inverse dynamics controllers, which are highly model based and therefore accurate modeling is a prerequisite.

2. LPV modeling

H-infinity control, as one of the typical methodologies in the framework of robust control conception, attracts our attention for its feasibility study of application in industrial robot motion control, not only because it favours multivariable model-based control design but also due to its inherent consideration of system robustness to unmodeled dynamics and parametric uncertainty. In recent years, as the extension of linear optimal H-infinity control methods and Linear Matrix Inequalities (LMI), LPV gain-scheduling techniques have evolved into a promising and efficient tool for solutions to modern nonlinear control applications. Industrial robot motion control cannot be more suitable for this method since, besides the unknown dynamics uncertainty discussed above, industrial robot also owns another well known dynamics problem, that is, rapidly varying dynamics resulting from changing configurations during quick movement in entire work envelope will bring forward a tricky issue for the controller regarding properly handling of such a parameter-varying system in an effective way. For example, as shown in Fig.1, with