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Review article

A review on model reference adaptive control of robotic manipulators

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ABSTRACT

The accuracy of the motion control for robotic mechanisms will have an effect on their overall performance. Under the condition where the robotic end-effector carries different loads, the motions for each joint of robotic mechanisms change depending on different payload masses. Conventional control systems possess the potential issue that they cannot compensate the load variation effect. Adaptive control, especially the model reference adaptive control (MRAC), has therefore been put forward to handle the above issue. Adaptive control is generally divided into three categories, model reference, self-tuning and gain-scheduled. In this study, the authors only focus on the model-reference approach. To the best of the authors' knowledge, very few recent research articles can be found in the area of MRAC especially for robotic mechanisms since robotic system is a highly nonlinear system, and it is difficult to guarantee the stability of MRAC in such system. This study presents a review and discussion on the MRAC of robotic mechanisms and some issues of MRAC for robotic mechanisms are also demonstrated. This study can provide a guideline for upcoming research in the field of MRAC for robotic mechanisms.

1. Introduction

The control problem for robotic mechanism is usually described as follows, provided an expected path, a numerical model of the mechanism and its interactions with surroundings, finds a control algorithm that delivers force or torque signals to the actuators, in this way the robotic mechanism is able to accomplish anticipated movement. The control design for a serial mechanical mechanism contains two major steps. A robotic end-effector travel path is first specified, e.g. making the end-effector move from position A to position B. From the movement trajectory of the end-effector and also via resorting to the inverse kinematics, the motions of the joints can therefore be determined so as to create the desired trajectory for the end-effector. The next step is to figure out the amount of torque that one has to apply to joints so that the joints are able to achieve the desired motion. The torque can be calculated based on inverse dynamic equations.

Controlling the robotic manipulator to conduct in a designated fashion is a tough matter since the robotic system is extremely nonlinear. Regarding robotic systems, the dynamic equations' coefficients contain joint and payload variables. These variables may be unknown or may even alter during the task. When a robotic mechanism is in motion, the joint variables change, and this can make the robotic system's dynamic equation alter throughout a task. For the purpose of having a higher repeatability and accuracy in the robotic system's performance, one needs to employ a control system (e.g. MRAC) which can take in the dynamic characteristic changes of the robotic system. Traditional control techniques treat a robotic mechanism as uncoupled linear subsystems; they are able to provide adequate performances at low speeds. However, for applications that require high-speed actions, they are no longer effective. The utilization of the PID control system for controlling sometimes may not promise system stability or optimal control for the system (Visioli, 2006). For the aim of addressing the above issue, one can consider to employ the adaptive control. MRAC is one of the most prevalent and well-used methodologies.

Adaptive control is able to adjust to a manipulated system with parameters that change constantly, or are originally unknown. Regarding non-adaptive control system, the control system is modelled on the basis of the system's priori data, in other words, we know the system and develop the controller only intends for that system and presume the changing phenomenon does not exist within the system. With respect to the adaptive controller, on the contrary, the controller does not have to rely on the prior data from the system, and if some random changes happen in surroundings, the controller is able to handle it through adjusting to the altered states. If one considers a system with a known transfer function, and one designs a fixed classical control system, the control system will maintain the specified parameters all the way to the point where it does not apply to the system anymore. It can be claimed that this control system relies on its structure and is modelled on a-priori knowledge, this is a non-adaptive control sys-

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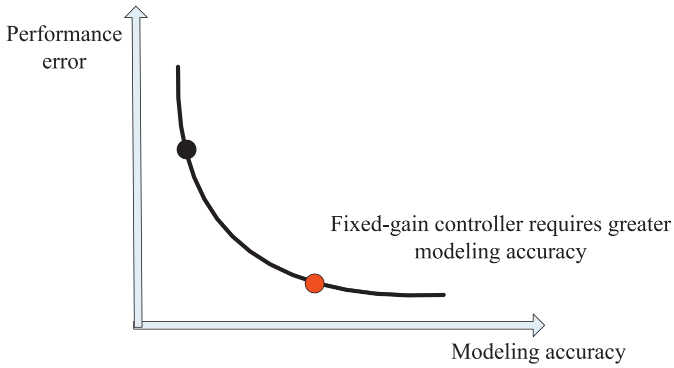

Fig. 1. Non-adaptive control.

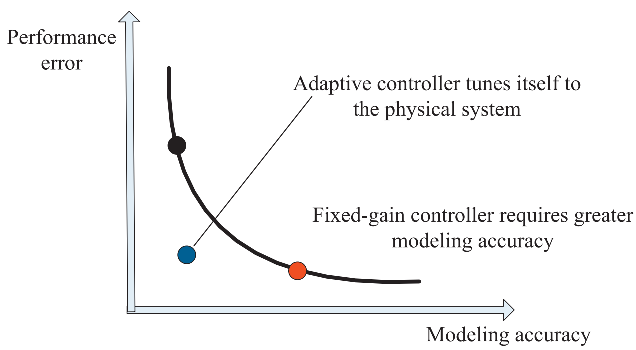

Fig. 2. Adaptive control.

tem. Notwithstanding, if the control system is relying on posteriori data, for instance, if the control system's parameters are changing, due to the system parameters' changes or due to the interferences originating from the surroundings, this control system is named adaptive. If the system faces uncertain interferences, or it is anticipated to endure changes in its parameters in a fashion that is unpredicted from the start, under this situation we employ adaptive control. Nevertheless, in other situations where we know how the system's working state is going to alter, taking an aircraft as an example, it is known that designing of the aircraft control system is influenced by the speed and altitude, and one expects it to travel at particular values for altitude and speed. Under this situation a controller is able to be designed for every single anticipated operating point and the different controllers can be interchanged each other, this is named gain-scheduling. In other scenarios where we know the system's parameters vary, but one also knows an extent for the parameter change, in this situation it is feasible to develop a fixed controller which is able to handle different changes of the parameters, and promise the stability, this type of control system is a robust control.

Regarding the non-adaptive control, from Fig. 1, it can be observed that under the situation where the performance error is improved, the modelling accuracy is also increased. Furthermore, it is believed that future is same with the present, disregarding changes in environment and dynamics, and structure damage.

For the adaptive control, it obtains a designated system performance asymptotically, the modelling accuracy performance is not compromised, i.e. adaptive control can guarantee the system performance regardless of the accuracy of the model, as demonstrated in Fig. 2, and more importantly, it can be self-improved when unforeseen and adverse conditions exist.

The adaptive control can be classified into the three types, MRAC, self-tuning and gain-scheduled, as illustrated in Fig. 3. The authors here primarily focus on the model-reference approach.

Regarding the MRAC, there is an input being given to the real and the reference systems, and the error among the real output and the reference model's output is generated. The error is then employed to modify the controller's parameters in order to make the error minimized. Fig. 4 illustrates such a control system.

As comparing to other control techniques, adaptive approach is more likely to perform better for a broad array of movements and loads. The asset of the MRAC is that one does not have to completely know the plant parameters, rather, the plant parameters' approximations can be employed and the adaptive control system resorts to prior input/output data to further improve these approximations. On the downside, there are two disadvantages for this type of control. The control system's stability performance is crucial because it is hard to develop a stable adaptation rule. The other issue one faces is that MRAC system depends on cancelling the non-linear segments via the reference model (Sutherland, 1987). In real situation, fully cancellation cannot be ensured, but the non-linear segments can be forged very small to the point where one is able to neglect them. MRAC technique was first presented in Whitaker, Yamron, and Kezer (1958), when the authors examined adaptive flight control system, utilizing a reference model to create an offset among the real and ideal behavior. The offset was utilized to alter the control system parameters for the purpose of having desired outcome regardless of changing system dynamics and uncertainties. The objective of employing an adaptive controller is to reach and retain a satisfactory degree in the control system performance when plant parameter variations exist. While a traditional feedback controller is primarily custom built for eliminating the impact of disturbances on the controlled variables, an adaptive controller is primarily custom built for eliminating the impact of parameter disturbances on the control system's performance.

2. Model reference adaptive control of robotic manipulators

2.1. General adaptive control

For a conventional controller, feedback is employed to reject the disruption impact that acts on the manipulated variables for the purpose of bringing these manipulated variables back to the ideal value. In order to do so, one determines the variables and compares the variables to the ideal values and an error can be generated. This error is provided to the control system. In these feedback systems, one is able to modify the control system parameters so that an ideal control performance can be accomplished. This is conducted on the basis of knowing a priori plant dynamics' information. In the cases where the plant dynamic models' parameters vary with respect to time, the traditional control is no longer able to handle it because the control performance can be deteriorated. In cases like this, one can resort to the adaptive control. A structured technique for designing distributed and adaptive control systems is demonstrated in Valente, Carpanzano, and Brusaferri (2011). Distributed architectures are visualized as separate units with conventional interfaces that can be altered and re-utilized not having the entire control framework been affected. While regarding the centralized control structures, every single modification of the machine configuration demands a large scale control system changes. In reconfigurable manufacturing system, modular and distributed structure is crucial for ensuring the ability of every unit or parts of the control to be adjusted in a situation where a hardware reconfiguration happens.

In Bi, Liu, and Baumgartner (2015), the authors illustrated the sustainable manufacturing based on the robotic system reconfiguration via employing robot modules. The modules are suction pump and adapters, end-effector, PLC and robot controller, sensors and power supply. Regarding the control, two different con-