Reduction of the effect of actuator saturation with periodic servo constraints

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Abstract

Actuator saturation is a well known and often unavoidable problem of many engineering systems. The actuators of a robotic system may temporarily saturate simply because it is physically not possible to provide the high torque demanded by the controller. In other cases, saturation can even be desirable for safety reasons. For example, in human friendly robotics low-power actuators can guarantee a harmless operation.

In the classical, industrial robotic settings the saturation of actuators has the unwanted effect of decreasing the positioning/trajectory following accuracy. When the operating conditions are well defined, careful task and trajectory planning can help to avoid actuator saturation, but there always will be a trade-off between selecting saturation prone operation conditions and productivity. When saturation is present, a control design is necessary that tries to reduce its unwanted effects. A classical solution is the so called anti-windup scheme, when the nominal controller is augmented with a compensator that takes into account the difference between the saturated and ideal control inputs.

A saturated system is unable to follow the prescribed trajectory exactly, which may also be seen as a consequence of temporary underaction of the robotic manipulator. This behaviour is studied in detail in [1], where the saturation of actuators is handled as a temporary reduction of the number of accessible independent control inputs, and the number of prescribed servo constraints [3, 5] is reduced accordingly.

To reduce the unwanted effects of actuator saturation, in the present work we propose the use of periodic servo-constraints. In many cases a slight modification of the servo-constraint is needed in order to control the otherwise unstable internal dynamics [3] of an underactuated system. One possible approach is the periodic variation of the servo constraint. For underactuated robots the usefulness of the method was proven in [2]. Here we further generalize the method for the case of actuator saturation, so the servo-constraints are systematically switched during actuator saturation to redistribute the load on them. When the actuators are not saturated, a general computed torque control scheme is applied to realize the desired motion. During saturation, we follow a similar method to what is described in in [1], with the essential difference that not only the number of servo constraint are reduced, but also new sets of periodically varied servo-constraints are introduced. These new servo-constraints should be chosen in such way that the relative degree [6] should not be changed with respect to the accessible actuators. We also note that with the proper selection of the switching pattern one might ensure that the violation of the inactive servo-constraints are minimized.

To demonstrate the applicability of the method and to compare the results with [1], a simulation study was conducted with a two-link manipulator shown in Fig. 1. In the presented example, the end-effector of the manipulator was commanded to follow the desired trajectory described by x_d and y_d. For this case, the prescribed motion is given by the servo-constraints $\phi_1 = x_\mathrm{TCP} - x_\mathrm{d}$ and $\phi_2 = y_\mathrm{TCP} - y_\mathrm{d}$, where the subscript TCP refer to the tool center point of the robot. The task was to follow a horizontal path, with time-displacement profile shown in Fig. 3a. During saturation, the servo-constraint is then formulated as $\phi = (1-\gamma)\phi_1 + \gamma\phi_2$ with γ defining the periodic switching pattern. As shown in Fig. 2, we selected gamma such that for i time steps the horizontal position and for k time steps the vertical position of the TCP was controlled.

The results of the numerical study are briefly summarized in Fig. 3 which shows the norm of the servo-constraints' violation. Due to the high acceleration around $t = 3[\mathrm{s}]$ the second actuator was driven to saturation. The results clearly show that the proposed periodic switching control strategy can effectively enhance the precision of the position control of systems with saturating actuators.

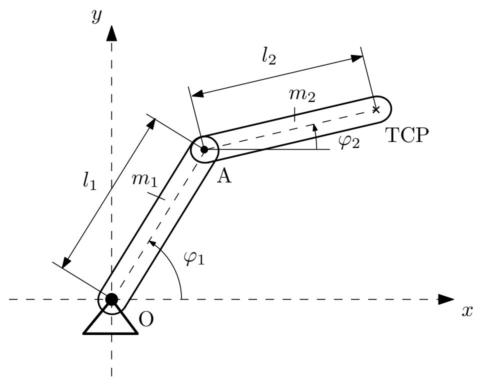


Figure 1: Two-link manipulator model

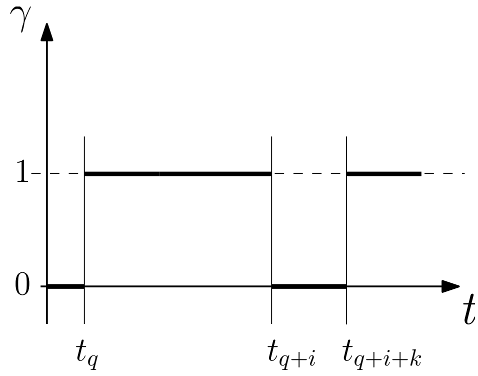
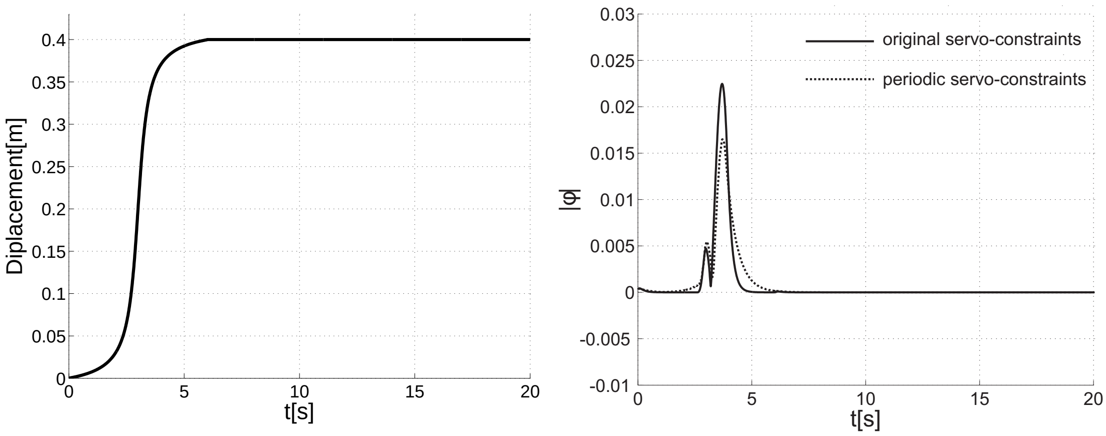


Figure 2: Switching pattern of servo-constraints



(a) Simulation with constant servo-constraints

(b) Simulation with periodic servo-constraints

Figure 3: Reduced effect of saturation

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