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Actuator Saturation Avoidance in Overactuated Systems

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Abstract—**The presence of redundant actuators in dynamic systems increases system efficiency and capability. An example of this increased capability is avoidance of actuator saturation at critical moments. Defining a system maximum efficiency function, this paper will transform the problem of avoiding actuator saturation into an optimization problem with the capability of on-line solution. The paper will also present and evaluate the solution of optimization problems with inequality constraints. Finally, the performance of the proposed system will be examined through simulation.**

Keywords-Actuator saturation avoidance, redundant actuator, on-line optimization, cooperating manipulator.

I. INTRODUCTION

Dynamic systems with redundant actuator(s) find applications in various fields of science and engineering. Industrial examples include different kinds of simulators, cooperating manipulators, and even certain chemical processes. The presence of redundant actuators provides a system with higher capabilities and in robotic systems, for instance, creates the possibility for tracking more rapid trajectories, which yields greater efficiency and increased capability in the system. One of the uses of redundant actuators is in avoiding actuator saturation at critical moments. In other words, under conditions where disturbance or rapid reference input variations cause control signals exceeding the capacity of certain stimulators, redundant actuators can take over to supply a portion of the input energy and thus prevent saturation of other actuators.

In this paper, the problem of avoiding actuator saturation is transformed to a problem of optimization and an on-line solution of the problem is presented.

The problem of actuator saturation under various conditions has been studied by a number of workers. Ting *et al* [1] presented a method of avoiding actuator saturation in a closed-loop robot with a faulty drive using reference trajectory change in time domain and slowing down the drive. The same authors extended their method to serial robots with faulty drives [2].

Many researchers have also studied the problem of optimization in systems with redundant actuators or additional DOFs. Nahon and Angeles [3] published a method on on-line optimization of energy with inequality constraints in closed-loop mechanisms. Their attempts concentrated on reducing the calculation time of optimization algorithms. Ding and Chan [4] used linear programming in minimizing overactuated robotic torques. Hosseinin and Keshmiri [5] transformed the problem of kinematic optimization for robots with additional DOFs assuming a barrier in the workspace to a problem with inequality constraints and solved it. Naghshineh and Keshmiri also developed a method based on controller structural design for the on-line solution of optimization problems [6].

II. STATEMENT OF THE PROBLEM

Saturation in most cases occurs as a result of physical limitations in the elements employed in dynamic systems. Saturation in control systems means the conditions where at least one physical element used in the control loop is used at its maximum efficiency at certain points in time. For instance, measuring sensors and their output preprocessing circuits, analog to digital converters, digital to analog converters, actuators, and driver circuits in the control system of a robot are physical elements that can be employed within given ranges and saturation occurrence in them is possible.

This paper investigates the phenomenon of saturation of actuators for overactuated systems such as cooperating robots. If the controller in these systems detects an actuator to be saturated or approaching its saturation limit will prevent the saturation of the element by either effecting greater energy in redundant actuators or by compensating for the deficit energy resulting from the actuator's saturation. This method has been studied by defining the maximum efficiency cost function and by transforming the saturation avoidance problem to an optimization problem.

Initially, a typical example of actuator saturation effect on the control system efficiency is presented and then a mathematical statement of the problem will follow. In later sections, the on-line solution of the optimization problem as well as numerical examples will be given.

III. SATURATION EFFECT ON TRACKING PERFORMANCE: A TYPICAL EXAMPLE

Imagine a four-bar mechanism with one DOF and two actuators as shown in Fig. 1. This system with an