

Multivariable Saturating Control and Anti-Windup Control for the Phantom 500 body Motion: A Comparison

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Abstract: Guidance and control systems for autonomous underwater vehicles (AUV) are developed separately : control systems are designed based on vehicle dynamics whereas guidance laws are based on kinematic relationships. During the design phase, a pragmatic approach consists in designing the control system with sufficiently large bandwidth to track the commands that are expected from the guidance system (the so called time-scale separation principle). This approach generates high gain control loops and high level peak command inputs. If the actuator saturation level is not taken into account explicitly, stability and performance of the closed loop systems are not guaranteed. This potential problem is particularly serious in the case of severe operating conditions of underwater vehicles: high maneuvering trajectories, precision station keeping, strong current disturbances. In this context, tight restrictions on the closed loop bandwidth (which may lead to actuator saturations) are expected.

Windup phenomena appears in the presence of actuator saturation constraints for controllers with slow or unstable dynamics. If numerous results can be used to analyse systems with input saturations, the controller design problem is more complex. An approach consists in avoiding actuator saturation which often leads to poor performance: the control system for the most part of operating conditions operates far from its full capacity. The first design method presented in this paper is based on absolute stability concepts. The saturation block is modeled as a sector bounded nonlinearity and the designed controller guarantee absolute stability against the nonlinearity. An alternative to this saturating control method is the anti-wind up method which consists in a two step design procedure. The principle is to first design the linear controller neglecting the saturation phenomena

ensuring desired control objectives (stability, performances). Then, the second design step is to add an anti-windup compensator to minimize the effect of the saturation in regards with the desired control objectives.

At first glance, it is unclear which methods performs better. The purpose of this paper is to demonstrate the advantages of these two control methods designing the body motion controller of the underwater vehicle Phantom 500. This vehicle is equipped with only one vertical and two horizontal thrusters, the number of degree of freedom is smaller than the number of actuators. A common pragmatic approach consists in designing three decoupled controllers for longitudinal speed motion, for diving motion and for steering motion. In this paper we consider only the design of the steering controller. The propellers are assumed to be speed controlled. We considered a simplified decoupled model for the heading motion and the surge motion. More precisely, we consider that all the linear and angular body-referenced velocities are zero except for surge and heading rate velocity, which are described by first order non linear models for acceleration inputs. In the case of the Phantom 500, the effort delivered by the left and right thrusters depends quadratically on the rotation speeds which can operate in the range $[0 - 1000]$ (rpm). Using a static precompensator (input linearization technique) the plant can be described as a linear model with an acceleration saturation block which can be modeled as a sector bounded nonlinearity. The two design are performed using $\mathbf{H}_\infty$ synthesis method which allows to ensure the stability against the whole nonlinearity and to shape several closed loop transfer functions. Robustness objectives such as stability margins and robustness to neglected large frequencies dynamics are taken into account explicitly.