Observer-based Funnel Heading Control with Prescribed Settling Time for Ships: Addressing Rudder Dynamics and Saturation

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This work presents an observer-based funnel heading control strategy for surface ships, designed to address the challenges of guaranteeing transient and steady-state performance under practical constraints such as unmeasurable heading rate, environmental disturbances, and rudder actuator saturation and dynamics. The content is based on a recently accepted IFAC conference paper and is extended here with further insights and adaptation to more complex and general nonlinear systems.

Using a backstepping-based funnel control framework, the proposed approach introduces a novel formulation for achieving prescribed transient and steady-state behavior while guaranteeing predetermined settling time. A state observer is proposed to estimate both the heading rate and the actual rudder angle from heading angle measurement alone. Additionally, environmental disturbances, modeled as unknown sinusoidal signals, are actively estimated and compensated for within the control loop.

The rudder actuator is modeled as a first-order lag with amplitude saturation. This nonlinearity is particularly relevant in practical ship control, where actuation limits must be considered. The method employs dynamic surface control to avoid derivative computations of virtual controls and defines performance funnels for all error variables. This ensures that the errors remain within pre-specified thresholds and achieve the desired settling time, even in the presence of mismatched uncertainties and limited actuation capability.

Closed-loop stability, accounting for the coupled dynamics of the ship, actuator, and observer subsystems, is rigorously established using Lyapunov-based analysis. It is shown that all closed-loop signals are uniformly ultimately bounded and that the tracking and intermediate errors remain confined within their respective performance funnels.

The proposed method is validated through numerical simulations using the well-known "Esso München" ship model under substantial environmental disturbances. The simulation results demonstrate satisfactory heading and heading rate tracking performance, adaptive disturbance rejection, and accurate estimation of unmeasured states, even in the presence of actuator saturation and dynamics.

In addition to presenting the core methodology, this talk will explore potential extensions of the proposed approach to more general and complex nonlinear systems, encompassing a broad class of practical applications, including mechanical, electrical, and maritime systems.

Keywords: Heading control, Funnel control, Prescribed performance, Rudder saturation, Rudder dynamics, Observer design