Immersion and invariance: A new tool for stabilization and adaptive control of nonlinear systems

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Abstract: A new method to design asymptotically stabilizing and adaptive control laws for nonlinear systems is presented. The method relies upon the notions of system immersion and manifold invariance and, in principle, does not require the knowledge of a (control) Lyapunov function. The construction of the stabilizing control laws resembles the procedure used in nonlinear regulator theory to derive the (invariant) output zeroing manifold and its friend. The method is well suited in situations where we know a stabilizing controller of a nominal reduced order model, which we would like to robustify with respect to higher order dynamics. This is achieved by designing a control law that asymptotically immerses the full system dynamics into the reduced order one. We also show that in adaptive control problems the method yields stabilizing schemes that counter the effect of the uncertain parameters adopting a robustness perspective—this is in contrast with most existing adaptive designs that (relying on certain matching conditions) treat these terms as disturbances to be rejected. It is interesting to note that our construction does not invoke certainty equivalence, nor requires a linear parameterization, furthermore, viewed from a Lyapunov perspective, it provides a procedure to add cross terms between the parameter estimates and the plant states. Finally, it is shown that the proposed approach is directly applicable to systems in feedback and feedforward form, yielding new stabilizing control laws. We illustrate the method with several academic and practical examples, including a mechanical system with flexibility modes, an electromechanical system with parasitic actuator dynamics and an adaptive nonlinearly parameterized visual servoing application.