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Backstepping controller synthesis and characterizations of incremental stability

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Incremental stability is a property of dynamical and control systems, requiring the uniform asymptotic stability of every trajectory, rather than that of an equilibrium point or a particular time-varying trajectory. Similarly to stability, Lyapunov functions and contraction metrics play important roles in the study of incremental stability. In this paper, we provide characterizations and descriptions of incremental stability in terms of existence of coordinate-invariant notions of incremental Lyapunov functions and contraction metrics, respectively. Most design techniques providing controllers rendering control systems incrementally stable have two main drawbacks: they can only be applied to control systems in either parametric-strict-feedback or strict-feedback form, and they require these control systems to be smooth. In this paper, we propose a design technique that is applicable to larger classes of (not necessarily smooth) control systems. Moreover, we propose a recursive way of constructing contraction metrics (for smooth control systems) and incremental Lyapunov functions which have been identified as a key tool enabling the construction of finite abstractions of nonlinear control systems, the approximation of stochastic hybrid systems, source-code model checking for nonlinear dynamical systems and so on. The effectiveness of the proposed results in this paper is illustrated by synthesizing a controller rendering a non-smooth control system incrementally stable as well as constructing its finite abstraction, using the computed incremental Lyapunov function.

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