

Nonlinear & Adaptive (Learning) Systems: A Building Block Approach; & Application in a Number of Areas

Nonlinear and Adaptive systems and their applications, especially in intelligent control, have attracted a lot of attention. Many paradigms and approaches have been proposed, and they rely mostly on analytical techniques that could be understood only by a few of those mathematically gifted. Lyapunov based (including the now popular integrator back-stepping) and estimation based schemes used commonly in adaptive control and other areas are very good examples that come under this category. In our work, we advance a new paradigm that we call the building block approach for Nonlinear and Adaptive Systems Design, and its application to a number of areas. This approach minimizes the need for complex analytical techniques (or moves the complexity away from a macro or global level to a micro or local level) in analyzing and/or designing such systems, and more importantly, gives us the ability to concentrate more on what we can achieve from such complex systems. Instead of looking at such systems from the classical analytical approach (dynamics to mathematical tools for characterization / stability testing to simulation and implementation), we look at such systems (and in fact, all nonlinear time-varying, NLTV, or non-autonomous systems) from an implementation (as electrical circuits) perspective¹ as shown in Fig. 1. Basically, it is built on answers to a number of fundamental questions: 1) what kind of electrical elements or building blocks we need to build complex NLTV circuits and what are their properties? 2) If the process of adaptation or learning is viewed from a circuits' perspective, what are the types of circuit realizations corresponding to this problem? 3) More importantly, can we use such elements, circuits formed (on a piece of paper) from such elements, and the dynamics resulting from such circuits as *templates* for further design, something similar to reverse engineering? The answers to these questions provide an elegant framework to handle the design of many systems in the nonlinear and time-varying domain.

We have applied this deceptively sounding simple approach to a number of application areas such as 1) Complex nonlinear techniques for signal processing and estimation, 2) Adaptive control that leads to results more complex than is possible with integrator back-stepping approach, 3) Complex chaotic systems design, and 4) Synchronizing chaotic systems design for secure communication, and 5) Nonlinear control of helicopters. In fact, most of these results have been derived by an army of just one person (the author) and absolutely no support from any agency and could easily and successfully be applied to many areas of nonlinear and adaptive systems if others would look at it with an open mind.

¹ We recognize that certain *macro or system level* properties of electrical circuits such as passivity and positive real (PR) functions have long been used in areas such as I/O stability, hyper-stability and positivity applied to model reference adaptive system design, and dissipative systems using Lagrangian and Hamiltonian models. Here we work at a *micro or element level* that provides us the flexibility to tailor the circuit / the dynamics to the application of interest.

NONLINEAR & ADAPTIVE (INTELLIGENT) SYSTEMS: MODELING, DESIGN, & CONTROL

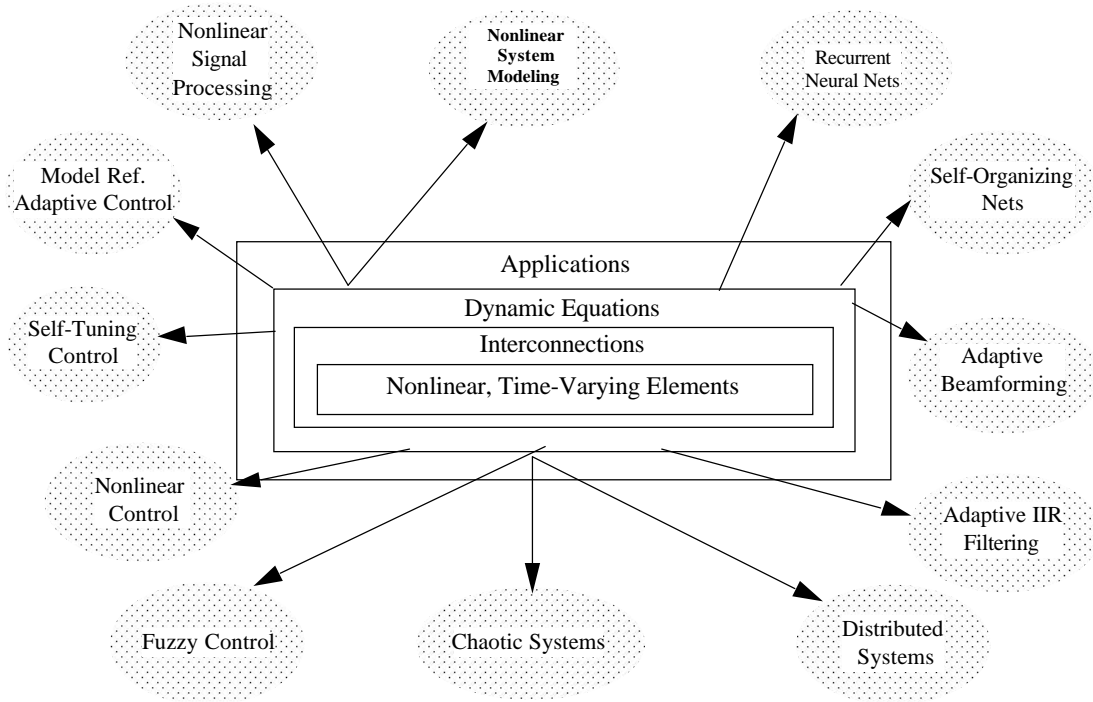
A Building Block Approach

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Central Theme: If a number of nonlinear, time-varying (passive, non-passive, active, single- and multi-port) elements (or building blocks) are available (i.e. their I/O relationships are known), then we can form a proper interconnection of selected type of elements to form circuits, and obtain dynamic equations that have the desired properties (globally, exponentially stable equilibrium point, for example). To design any system, we can then force the dynamics of that system to correspond to the dynamics of a properly connected circuit (a process similar to reverse engineering). The concept is simple, but powerful enough to be applied to a number of complex areas as shown in the figure.