Ph.D. Dissertation Research Proposal
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Date: May 13, 2013 (Monday)
Time: 9:30 AM
Room: ECE 202

Pointwise Stabilization and Control of a Class of Nonlinear Systems via State-Dependent Transfer Function

ABSTRACT

Real systems are inherently nonlinear. But the subject of nonlinear systems in control system design is an art rather than a science. There is no unified analysis and design framework for general smooth nonlinear systems. All the available theory and design tools such as linear algebra are based on linear system models; the only models that obey the principle of superposition. Because superposition principle does not apply to nonlinear systems, the model of these systems cannot be used directly as inputs in the available linear design methods. Even where it is possible to develop a custom nonlinear model-based control, the large amount of signal processing resource it takes to implement it, is usually the reason the approach may not be cost effective or practical. The high cost of signal processing resource for implementing controls has been one of the motivations for approximating nonlinear systems in small range of their signals with the linear time-invariant (LTI) model. The relatively small signal processing resource it takes to implement a fixed gain controller that results from a design based on an LTI model has been one of the advantages. The second equally important motivation is the availability of very well-understood linear system theory for analysis and design as long as the model is LTI. However, in the world today cost of signal processing resource is low, thanks to availability of powerful high-speed, low-cost microprocessors. The fixed gain controller benefit of designs based on an approximate LTI model is no longer a benefit considering the performance penalty that goes with it. For example, with a fixed gain controller, the performance of the real nonlinear system usually degrades when the operating range gets out of those small bounds assumed in deriving the approximated LTI design model. This does not have to be the case nowadays. With the cheap signal processing available, the fixed gain controller paradigm based on an approximate LTI model should be changed to a variable gain controller approach based on the real nonlinear model of physical systems. The more accurate design model should translate in the variable gain controller to a better performance with the additional signal processing resource usage. The objective of this research thesis is to investigate this new approach where emphasis is placed on model accuracy at expense of more signal processing resource in the controller implementation. Our research explores an on-line (pointwise) control system scheme that is applicable to a common class of general smooth nonlinear systems. These are systems that can be described using a kind of virtual transfer function model; a state-dependent transfer function (SDTF). These are nonlinear systems that are linear in their control input. Systems in this class are common. Any unforced nonlinear system in which one can find an external and appropriate control input that enters linearly into its unforced nonlinear equation. There are examples in biomedical devices, like artificial
pancreas and HIV AID drug delivery system, in mechanical systems such as robot arms, overhead crane and pendulum systems, in electrical circuits, like phase-locked-loops (PLL) and circuits with voltage or current dependent passive elements. Our investigation is limited to this specific class; however, we see the potential for future extensions leading to a unified design framework for all general smooth nonlinear systems.

We begin our research by defining and deriving the SDTF model for this class of nonlinear systems. We explore the implications of this new modeling perspective. For example, a system in this class can be thought of as pointwise LTI, or as having zeros and poles that vary as the system state changes. This new perspective suggests a “non-stationary” nature of nonlinear systems as opposed to “stationary” nature of LTI systems.

The SDTF model can only be evaluated as the state of the system is measured while the system is under control so for this control we propose a pointwise stabilizing controller (PSC). This is truly a nonlinear adaptive controller implemented digitally with signal processing resources. We will demonstrate that with this controller, pointwise stability is guaranteed for this class of nonlinear systems. We will demonstrate this and validity of our proposed method by simulation and real experiment. For the experiment we shall build a simple inverted pendulum (a nonlinear system) driven at its pivot by a dc motor. We shall design and implement a PSC for this experimental setup on Texas Instrument’s 32-bit floating point Delfino microcontroller. Connected to the microcontroller via an RS232 interface, will be test computer running communication, control and data acquisition software. And the analysis, design and simulations shall all be carried out in MATLAB/SIMULINK environment.

COMMITTEE MEMBERS

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BIOGRAPHY

Roger Kwadzogah (rkk2@njit.edu) received his B.S. and M.S. degrees from New Jersey Institute of Technology (NJIT), in 1997 and 1999, respectively both in electrical engineering. He worked as both software and electrical engineers at Metrologic Instrument Inc., and Quad Systems Corp., from 1999 to 2002. From 2002 to 2006 he worked as electrical engineer at Smiths Aerospace Actuation Systems. He worked for Siemens Healthcare Instruments as both Software and Hardware engineer from 2006 to 2010. Roger also worked as firmware consultant engineer for Schlumberger Oilfields at their Princeton Technology Center (PTC) from May 2010 to June 2011. His research interests include nonlinear and adaptive controls and implementations on DSP and microprocessor platforms.
RELEVANT PUBLICATIONS

