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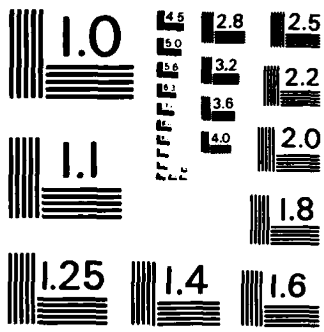

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Identification of Linear, Bilinear and Polynomial Input-Output Differential and Differential-Delay Systems. Time Delay Estimation in Received Signals. Feedback Stabilization of State Delayed Control Systems.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Research is summarized for a projected integral equation error technique used in the parameter identification of differential-delay equation models, including the time delay estimation problem for received signals. Current research on a fresh look at the Shinbrot method of moment functionals is described relating to the modeling and identification of linear, bilinear and polynomial input-output differential systems. Current research is also described for the feedback stabilization of state delayed control systems using a reducing transformation technique.

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CONTROL AND IDENTIFICATION OF TIME VARYING SYSTEMS

Period covered: June 30, 1984 to June 29, 1985

from

Allan E. Pearson
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Brown University
Providence, RI 02912

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Principal Investigator

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Executive Officer
Division of Engineering

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1. Summary of Progress and Continuing Research

The long-range objective in this research program remains to develop step-by-step identification/control strategies for various classes of dynamical systems which utilizes input-output data in block data form over short time intervals for parameter identification purposes, while incorporating feedback stabilization control algorithms appropriate to the class of dynamical systems at hand. Hence, the identification portion of this objective is to obtain computationally feasible algorithms for parameter identification which can work with time limited data, while the controls research is aimed at developing feedback stabilization methods for those classes of dynamical systems which do not have well established techniques such as systems described by differential-delay equations. The publications and papers-in-press listed in Section 2 for this period, Ref. [1]-[8], are concerned in one way or another with this objective.

Estimating unknown time delays is a problem which arises in a variety of applications such as tracking the position of a signal source, or the control of an incompletely known system modeled by differential-delay equations. References [1] and [2] pertain to this problem with [1] devoted to the problem of time delay estimation involving received signals. Here it is shown that several existing approaches, specifically the phase data, the generalized cross correlation and the parameter estimation methods, can be closely related. A rederivation of the parameter estimation approach revealed some insights about its biasedness in delay estimation and raises questions about its superiority over the usual cross correlation method. With the confusing simulation results published in the literature, a fair experimental evaluation is considered important. In this vein it is demonstrated (cf. Table III in [1]) that the use of a system identification approach may be justified when a more complicated model involving different channel dynamics is considered, especially if the data is time limited. A projected integral equation error technique, developed in [2], is then shown under certain noise corrupted data conditions to yield significantly smaller estimation errors than the cross correlation method when the data is time limited.

The technique developed in [2] is the culmination of an effort to decouple the estimation of pure time delays from the remaining system parameters when faced with the problem of identifying a system belonging to a class of models characterized by differential-delay equations. The motivation for this quest is that the unknown time delay parameters are the most difficult to identify in a differential-delay equation (DDE) system owing to their inherent nonseparability from the data in the DDE model. Thus, a least squares formulation which decouples their determination from the remaining system parameters has the potential for easing the difficulty of the overall problem since once these parameters have been estimated, the remaining system parameters can be determined by a variety of methods that pertain to models which are linear and separable in the parameters. It is believed that this potential has been realized with the results presented in [2] by virtue of the comparisons made with several existing methods including the maximum likelihood development of Wong,[1] and the method of Banks, Burns and Cliff [2] in which the DDE is replaced by an approximating system of higher order ODE's using linear semigroup theory.

References [3] through [7] are based on a fresh look at an old technique due to Shinbrot[3] for replacing an ordinary differential equation defined over a finite time interval by an algebraic equation in the parameters via the use of so-called "modulating functions." By building up a set of modulating functions from Fourier based commensurable sinusoids, it has been possible to treat a series of problems in the modeling and identification of certain input-output differential

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[1] Wong, E. (1980). Parameter identification of linear discrete stochastic systems with time delays. *In* C. T. Leondes (Ed.), *Contr. Dyn. Syst.*, **16**. Academic Press, 131.

[2] Banks, H. T., J. A. Burns and E. M. Cliff (1981). Parameter estimation and identification for systems with delays. *SIAM J. Contr. Optim.*, **19**, 791.

[3] Shinbrot, M. (1957). On the analysis of linear and nonlinear systems. *Trans. of the ASME*, 547.

systems, both linear and nonlinear, in which the underlying calculations entail determining a finite set of Fourier coefficients of the input-output data on a finite time interval. Since these coefficients can be determined with great accuracy via an appropriate discrete Fourier transform (DFT) and since the latter can be efficiently calculated via a fast Fourier transform (FFT) algorithm, one motivating factor in this research has been the computational advantage of providing a "fast algorithm" for the underlying computations. The problems considered thus far include a deterministic least squares identification for polynomial input-output differential systems of known order [3], an "efficient" method for the parameter identification of bilinear input-output differential systems using sinusoidal probing signals which entails essentially the same underlying computation as attends a linear differential system of the same order [4], structure determination for polynomial input-output differential systems (including the problem of determining the order of the polynomials on the input-output variables) [5], order determination for bilinear input-output differential systems [6], and a special consideration of linear differential systems which includes a maximum likelihood estimate for eliminating the bias when performing the identification in a recursive mode [7]. Reference [7] also includes extensive simulation data to verify the intuitive notion that a judicious choice of modulating function frequencies can enhance the signal to noise ratio when performing the least squares identification in a noisy environment. These papers are part of an ongoing research effort into the parameter identification of dynamical systems using time limited input-output data.

Another research area currently under investigation is that of devising stabilizing feedback control laws for DDE systems with delayed states and delayed controls. Our approach is via a "reducing transformation" which facilitates the design of the feedback control using delay-free methods [8]. This can be regarded as a nontrivial extension of our earlier work on feedback control for DDE systems with delayed controls.[4] A number of papers are currently in preparation which include robustness issues of the stabilizing feedback controls, observers and a separation principle for realizing the control using output feedback, and extensions to more general systems like systems with distributed delays in both the state and control variables.

2. Publications and Papers In Press

[1] Wuu, C. Y. and A. E. Pearson (1984). On time delay estimation involving received signals. *IEEE Trans. on Acoustics, Speech and Signal Processing,* **ASSP-32,** No. 4, 828.

[2] Pearson, A. E. and C. Y. Wuu (1984). Decoupled delay estimation in the identification of differential delay systems. *Automatica,* **20,** No. 6, 761.

[3] Pearson, A. E. and F. C. Lee (1985). On the identification of polynomial input-output differential systems. *IEEE Trans. on Automatic Control,* **AC-30,** No. 8, 778.

[4] Pearson, A. E. and F. C. Lee (1985). Efficient parameter identification for a class of bilinear differential systems. *Proceedings of the Identification 85 Symposium of IFAC,* University of York, UK, July 3-7, 1985.

[5] Pearson, A. E. (1985). On structure determination for polynomial input-output differential systems. *Proceedings of the Fourth Yale Workshop on Adaptive Systems Theory,* Yale University, New Haven, CT, May 29-31, 1985.

[6] Pearson, A. E. (1985). Order determination for a class of bilinear differential systems. To be presented at the ASME WAM, Miami, FL, Nov. 1985.

[7] Pearson, A. E. and F. C. Lee. Identification of linear differential systems via Fourier based modulating functions. Invited paper submitted to the new journal: *Control-Theory and Advanced Technology.*

---

[4] Kwon, W. H. and A. E. Pearson (1980). Feedback stabilization of linear systems with delayed control. *IEEE Trans. on Auto. Contr.,* **AC-25,** 266.

[8] Fiagbedzi, Y. A. and A. E. Pearson (1985). Feedback stabilization of state delayed systems via a reducing transformation. To be presented at the IEEE CDC, Ft. Lauderdale, FL. Dec. 1985.

3. Ph.D. Theses

Lee, F. C. ***Time Limited Identification of Continuous Systems Using the Modulating Function Method.***

Ph.D. Thesis, Division of Engineering, Brown University, May 1985.

Fiagbedzi, Y. A. ***Stabilization of a Class of Autonomous Differential Delay Systems.*** Ph.D. Thesis, Division of Applied Mathematics, Brown University, May 1985.

4. Supported Personnel

Y. A. Fiagbedzi	Research Assistant
F. C. Lee	Research Assistant
A. E. Pearson	Professor of Engineering

5. Invited Presentations and Seminars

March 20: National Chiao Tung Univ., Taiwan.

"Identification and Control of DDE Systems."

March 26-April 2: Seoul National Univ., Korea. A series of lectures on system parameter identification and control carried out under the auspices of an NSF Division of International Programs grant.

April 3: Agency for Defense Development, Korea.

"Adaptive Control of a Tactical Missile System."

April 9: Kyoto Institute of Technology, Japan.

"Identification and Control of DDE Systems."

May 31: Yale Univ., Fourth Yale Workshop on Adaptive Systems Theory.

"On Structure Determination for Polynomial Input-Output Differential

Systems."

June 26: Univ. of Warwick, England.

"Feedback Stabilization of State Delayed Control Systems."

June 28: Univ. of Manchester, Institute of Science and Technology, England.

"Feedback Stabilization of State Delayed Control Systems."

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--27 -  ABSTRACT    CURRENT RESEARCH IS SUMMARIZED FOR THE PARAMETER
--      IDENTIFICATION OF A CLASS OF POLYNOMIAL DIFFERENTIAL SYSTEMS VIA
--      THE MODULATING FUNCTION METHOD. THE UNDERLYING COMPUTATIONS INVOLVE
--      CALCULATING A FINITE NUMBER OF FOURIER COEFFICIENTS OF THE INPUT-
--      OUTPUT DATA WHICH CAN BE DETERMINED USING A FAST FOURIER TRANSFORM
--      ALGORITHM. CURRENT RESEARCH IS ALSO DESCRIBED FOR DEVISING
--      STABILIZING FEEDBACK CONTROL LAWS FOR A CLASS OF DIFFERENTIAL-DELAY
--      SYSTEMS USING A SPECTRAL FACTORIZATION OF THE STATE SPACE.
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