SUMMARY OF RESEARCH RESULTS OF THE 1980 US-AUSTRALIAN JOINT SEMINAR/WORKSHOP ON SYSTEMS THEORY AND SOME APPLICATIONS

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Abstract

The Research Topic Summaries of the 1980 US-Australian Joint Seminar/Workshop on Systems Theory and Some Applications are presented.

I. INTRODUCTION

On March 24-38, 1980, the US-Australian Joint Seminar/Workshop on Systems Theory and Some Applications was held at the University of Newcastle in Newcastle, Australia, under the sponsorship of the US National Science Foundation and the Australian Department of Science and the Environment. The Seminar/Workshop had as its purpose "to undertake a study of new applications and collaborative US-Australian undertakings in solving and presenting open problems using recent results in mathematical systems theory". For this six US and ten Australian researchers, along with three third country participants, were brought together presenting 35 papers with 17 devoted to theory and 18 to applications.

From the resulting discussions seventeen open research problems were identified and catalogued; these are given in Section II below. To go along with these twelve specific topics for US-Australia cooperation were identified, these being:

(1) "Pole Placement and Stabilization by Output Feedback".
(2) "Fundamental Problems of Filter Theory".
(3) "Nonlinear Filtering".
(4) "Microwave Neuristors".
(5) "Adaptive Prediction of Control".
(6) "Training Aids for the Hearing Handicapped".
(7) "Nonlinear Fluctuation-Dissipation Theorem".
(8) "Adaptive Control".
(9) "Noisy Generating Electronics".
(10) "Digital Filters with Randomly Time-varying Coefficients".
(11) "Modelling of Nonlinear 'Badly Behaved' System".
(12) "Spectral Transformation in Frequency Multiplication for Hearing Impaired".

A full report on the meeting, including abstracts of the talks given and summaries of important advances presented in the talks, has been made to NSF.

II. OPEN RESEARCH PROBLEMS IDENTIFIED

Here we present the seventeen research topics thought to be important enough for specific identification. Information is given on each such that one interested in the topic has a lead into the area. The primary proposer of each topic area is given with their addresses, and those of all attendees listed in the appendix.

Topic 1:
(1) Title - LINEAR SYSTEMS THEORY
(2) Name of Presenter: B. Anderson
(3) Problem: Given Markov Coefficients of a rational transfer function, with upper bound on its degree, give a straightforward finite test for positive realness.
(4) Outline of Theory:
a. There exists a nonstraightforward test that is finite (realized using Hankel, or computed from checking the transfer function).
b. There exists a straightforward test which is infinite.(Infinite Toeplitz matrices found from Markov coefficients should be positive definite).
(5) Background Needed:
a. Guillemin book
b. Szego Orthoganal Polynomials
c. Connection between positive real functions and spectra

Topic 2:
(1) Title - ROBUST ADAPTIVE CONTROL
(2) Name of Presenter: B. Anderson
(3) Problem: Show that if an unknown plant is approximately linear, finite dimensional, an adaptive control procedure will work.

(4) Outline of Theory:
Need to establish stronger stability results for the case when unknown plant is linear, finite dimensional, e.g. exponential asymptotic stability or uniform global asymptotic, which will imply that perturbation of plant will not destroy qualitative behavior of the algorithm.

Topic 3:
(1) Title - OPTIMIZATION OF SYSTEMS INCLUDING HUMANS
(2) Name of Presenter: R.E. Bogner
(3) Problems: A. Choice of optimal configuration of communication; B. Formulation of objective functions; C. Techniques of evaluation of such systems (R.W.N.)
(4) Outline of Theory:
Presently there is little known concerning theory of systems in which a human acts as part of the system--the area is wide open for systems theory research. (R.W.N.)
(5) Background Needed:
a. Classical and infinite-dimensional control theory (R.W.N.)
b. Basic physiology (R.W.N.)
c. Fuzzy systems theory (R.W.N.)

Topic 4:
(1) Title - POLE ASSIGNABILITY BY OUTPUT, MEMORYLESS FEEDBACK OVER $\mathbb{R}$
(2) Name of Presenter: C.I. Byrnes
(3) Problems: (m=#inputs, p=#outputs, n= McMillan degree)

a. If m=2,p=4,n=8 is the generic system pole assignable?
b. If m=3,p=3,n=9 is the generic system pole assignable?
c. If mp=n, is the generic system stabilizable?
d. If a system is pole-assignable, given the desired closed loop characteristic polynomic p(s) is the requisite gain K rationally computable in p(s)?

(4) Outline of Theory:
These questions can all be cast in the setting of real algebraic teometry, one possible technique for studying the solubility of these equations is classical elimination theory. Although this was carried out (see [a]) explicitly for m=p=2,n=4, in general one desires a route avoiding this long and tedious process. Decision algebra has been raised as one viable alternative (see [b]), and a careful investigation of the equations shows that another alternative is by use of the Schubert Calculus. (see [c], [d]).
(5) Background Needed:
a. Algebraic Geometry, elementary concepts and intersection theory.
b. Decision Algebra
c. Basic Algebraic System Theory
(6) Main References:
a. J.C. Williams - W.H. Hesselink, 1978 IFAC Proceedings
b. B.D.O. Anderson, N.K. Bose and E.I. Jury, IEEE AC-20, Feb. 1975.
c. C.I. Byrnes, Proc. NASA-NATO Adv. Study Inst., Harvard Univ., June 1979.
d. R.W. Brockett, C.I. Byrnes, to appear in special issue on multivariable linear systems, IEEE Trans. AC, Dec. 1980.

Topic 5:
(1) Title - ADAPTIVE CONTROL
(2) Name of Presenter: G.C. Goodwin
(3) Problems: A. Timevarying and/or nonlinear systems; B. Unstable and nonminimum phase stochastic systems; C. Rates of convergence; D. Accuracy and finite word length constraints.
(4) Outline of Theory:
Lyapunov stability, Martingales, stochastic linear systems theory. Recursive parameter estimation algorithms. Asymptotic efficiency. Order determination. Estimation of time delays. Pole assignment.
(5) Background Needed:
a. Stability theory.
b. Martingales.
c. Stochastic control.
(6) Main References:
a. Feurer and Morse "Adaptive Control of Single Input Single Output Linear Systems," IEEE Trans. Auto Control, Vol. AC-23, No. 4, August 1978.

b. Goddwin, Ramadge and Caines "Discrete Time Multivariable Adaptive Control," IEEE Trans. Auto. Control, June 1980.
c. Goodwin, Ramadge and Caines, "Discrete Time Stochastic Adaptive Control," SIAM Jnl. on Control and Optimization, 1980.
d. Astrem, Borsson, Ljung, Wittermas "Theory and Application of Self Tuning Regulations," Automatica, 10, pp. 457-476, 1977.

Topic 6:
(1) Title - NON EUCLIDEAN FUNCTIONAL ANALYSIS AND GAIN EQUALIZATION
(2) Name of Presenter: J.W. Helton
(3) Problem:
The basic problem is to design an amplifier with flat gain from a transistor with frequency dependent gain. Solved problems include a unilateral transistor equalized losslessly. "Major" unsolved problems involve stability of amplifiers and passive equalization.
(4) Outline of Theory:
The first step is to find a very condensed parameterization for all amplifiers one wants to consider. This takes a lot of work but a fairly general procedure is now developed for lossless equalizers. The parameterizing set turns out to be all functions

satisfying an interpolation condition. One uses the existing theory of interpolation problems and needs to develop more.

(5) Background Needed:
a. Most college graduates in E.E. can follow the problem and result.
b. Research uses about everything in the complex variables side of operator theory.

(6) Main References:
a. "Orbit Structure of Mobius Transformations acting on H^s", Adv. Math Suppl., 1979.
b. "Poincare Distance of Function to H^s", J. Fun. An., to appear.
c."A Mathematical View of Braodband Impedance Matching", IEEE CAS Annual Meeting, New York, 1978.
d. "Gain Equalization Directly from Data," to appear.

Topic 7:

(1) Title - STOCHASTIC MODELLING OF DRUG-RECEPTOR INTERACTION

(2) Name of Presenter: D.G. Lampard

(3) Problems: A. Effects of agonist and antagonist concentrations at neuromuscular junctions (NMJ); B. Effects of forward and backward rate constants (for reactions at NMJ); C. Modelling of direct channel blocking by non-depolarizing muscle relaxants; D. See above, on synaptic noise fluctuations.

(4) Outline of Theory:
The interaction of a number of drugs with a finite population of receptor sites is modelled as a multidimensional birth and death process using the backward Kolmogorov equations. These equations are solved explicitly for the transition probabilities of the process and in particular the covariance function for agonist-receptor bonds is derived.

(5) Background Needed:
a. physiology of the NMJ.
b. stochastic process techniques.
c. some theory of Krawtchovic polynomials.

(6) Main References:
a. Karlin, S., & McGregor, J., (1958), J. Math. Mech., 7, 643-662.
b. Barrett, J.F.,& Lampard, D.G., (1955), IRE Trans. Inform. Th., IT-1, 10-15.
c. Lampard, D.G.,(1975), Circuit Th. & Applications, 1,31-48.
d. Kac, M., (1954), Random Walk & Theory of Browinian Motion in "Selected Papers on Noise and Stochastic Processes," Ed. N. Wax(Dover).

Topic 8:

(1) Title - STABILIZABILITY OF SYSTEMS

(2) Name of Presenter: N. Levan

(3) Problems: a)Output stabilizability; b)Boundary input stabilizability; c)Internal stability and structural theory of nonfinite dimensional systems.

(4) Outline of Theory:
Theory of p.d.e.'s via the semigroup technique in which the controller is unbounded--e.g. via sensors--Perturbation theory of semigroup by unbounded operators. New concept of stability-model theory of operators.

(5) Background Needed:
a. Semigroup theory.
b. P.D.E., sobolev spaces.
c. Boundary control theory.

(6) Main References: a. Applied Functional Analysis--A.V. Balakrishnan, Springer-Verlag, 1977.; b. Siam J. Control and Optimzation, J. Applied Maths & Optimization, J. Diff. Equations, (last three years)

Topic 9:

(1) Title - SYSTEM IDENTIFICATION/APPLICATION TO COMMUNICATION SYSTEMS

(2) Name of Presenter: J.B. Moore

(3) Problems: A. Extend globally convergent adaptive N-step ahead prediction/control/identification to non-minimum phase plants in the control case; B. Extend Detection/Least Squares for robust identification by providing a more complete convergence analysis.

(4) Outline of Theory:
a. Structure problems so that Martingale convergence theorems can be applied.
b. Geometric interpretation of parameter estimation in processing measurement hyperplanes by detection/averaging in parameter space.

(5) Background Needed:
a. Stochastic processes/least squares theory/control cummunication systems.
b. Globally convergent adaptive N-step ahead prediction/control/identification
c. Detection/least squares for robust identification.

(6) Main References: a. R. Kumar and J.B. Moore, "Convergence of Adaptive Minimum Variance Algorithms via Weighting Coefficient Selection", University of Newcastle, Technical Report EE7917, August, 1979; b. R. Kumar and J.B. Moore, "Inverse State and Decorrelated State Stochastic Approximation", University of Newcastle, Technical Report EE7808, August, 1978. (To appear in Automatica); c. R. Kumar and J.B. Moore, "Detection Techniques in Least Squares Identification", University of Newcastle, Technical Report EE7909, July, 1979.

Topic 10:

(1) Title - ADAPTIVE HEARING AIDS

(2) Name of Presenter: R.W. Newcomb

(3) Problems:A. Determination of signal transformations for individual hearing loss and factors changing in short term B. Control system specification to realize these transformations;C. Integrated circuit realizations of adaptive

hearing aids.

(4) Outline of Theory:
Hearing conditions change with the state of the human and the environment on a minute by minute basis. A theory, completely missing now, is needed to evaluate the conditions and reflect them into electronic hearing aids. Toward this the theories of adaptive control and nonlinear frequency transformations in the presence of parameters are applicable.

(5) Background Needed:
a. Hearing-Aid theory.
b. Adaptive control.
c. Integrated circuit electronics.

(6) Main References:
a. L.D. Braida, et. al., "Hearing aids - A Review of Past Research on Linear Amplification, Amplitude Compression, and Frequency Lowering," American Speech-Language-Hearing Association, ASEA Monograph 19, April 1979, pp. 87-113.
b. R.E. Bogner, "Frequency Division in Speech Bandwidth Reduction," IEEE Transactions on Communication Technology, Vol. COM-13, No. 4, December 1965, pp. 438-451.
c. F.T. El-Mokadem and R.W. Newcomb, "A System that Transforms the Speech Spectrum for the Partially Deaf," Record of the 1977 IEEE International Conference on Acoustics, Speech and Signal Processing, Hartford, May 1977, pp. 252-254.

Topic 11:

(1) Title - SEMISTATE CHARACTERIZATION OF CIRCUITS

(2) Name of Presenter: R.W. Newcomb

(3) Problems: A. Develop efficient means of setting up semistate equations; B. Obtain synthesis techniques in terms of semistate equations;C. Develop characterizations in terms of the semistate (as controllability, stability, etc.); D. Reduce other descriptions to canonical semistate ones.

(4) Outline of Theory:
The canonical semistate equations are
$\alpha\dot{x}+\beta(x,T)=\mathcal{D}u$, u=input , x=semistate
$y=Fx$, y=output, $\alpha,\mathcal{D},F$,constant
These are set up from circuits by the use of equivalences and circuit analysis. For design one would like to set up these equations from desired input-output relations.

(5) Background Needed:
a. State-variable theory.
b. Generalized inverse knowledge
c. Basic circuit theory

(6) Main References:
a. B. Dziurla & R. Newcomb, "The Drazin Inverse and Semi-State Equations," Int. Symp. on Math. Thy. of Networks & Systems, 1979, pp. 382-389.
b. M.P. Drazin, "Pseudo-Inverses in Associative Rings and Semi-groups," The Amer. Math. Monthly, Vol. 65, No.7 Sept. 1958, pp. 506-514.
c. C.F. Klamm, Jr., B.D.O. Anderson and R.W. Newcomb, "Stability of Passive Time-Variable Circuits," Proc. IEE, Vol. 114, No. 1, Jan. 1967, pp. 71-75.
d. R.W. Newcomb, "The Semistate Description of Nonlinear Time-Variable Circuits," IEEE Trans. on CAS, Jan. 1981.

Topic 12:

(1) Title - OPTIMUM FLAT DELAY FILTER CHARACTERISTICS

(2) Name of Presenter : K.K. Pang

(3) Problem: To find the optimum flat delay filter characteristics of realizable filters.

(4) Outline of Theory:
The problem of finding filter characteristics that produce flat delay in the passband can be formulated as a constrained optimization problem. It can be solved by non-linear programming techniques.

(5) Background Needed:
a. Filter theory.
b. Optimization by vector space methods.
c. Finite-element methods.
d. Non-linear programming techniques.

(6) Main References:
a. M. Hibino, Y. Zshizaki, H. Natauabe, IE^{3}CAS.
b. D.G. Luenburger, John Wiley '68.
c. G. Hadby, Linear & quadratic programming.

Topic 13:

(1) Title - HOMOTOPY AND STABILITY

(2) Name of Presenter: R. Saeks

(3) Problems:A. Develop necessity conditions for stability;B. Develop a degree theory;C. Formulate control system compensation techniques.

(4) Outline of Theory:
Classical control theory is extended to distributed, time-varying, and nonlinear systems via abstract, homotopic techniques. The open problems deal with extending the classical applications of Nyquist theory to these classes of systems.

(5) Background Needed:
a. Functional analysis.
b. Control theory.
c. Stability theory

(6) Main References:
a. Saeks, Stability & Homotopy, in Alternative to Multivariable Control, Chicago, NEC, 1979.
b. Saeks, "The Encirclement Condition and its Generalization", Trans. of IEEE, Vol. CAS-21, 1975.

Topic 14:

(1) Title - STABILITY OF MULTIDIMENSIONAL DIGITAL FILTERS

(2) Name of Presenter:R. Saeks

(3) Problems:A. Numerical stability tests; B. Design of stable multidimensional filters;C. Parallel implementation of

multidimensional filters;D. Holf-plane filter theory.

(4) Outline of Theory:
Powerful stability analysis techniques: We need to develop design theory and implementation techniques.

(5) Background Needed:
a. Filter theory
b. Several complex variables

(6) Main References:
a. Rader, etal, Survey of Digital Filtering Literature, IEEE Press.
b. DeCorli, Murray, Saeks, Multivariable Nyquist Theory, Int. Jour. on Cont., 1977.

Topic 15:

(1) Title - NON LINEAR MODEL FOR SOME PERCEPTUAL SYSTEMS WITH IMMEDIATE APPLICATIONS TO THE HEARING IMPAIRED

(2) Name of Presenter: M.B. Waldron

(3) Problems: A. Coding of speech for the input to the tactile system so that optimal system processing can be attained;B) Optimal spatial tactile display in accordance with A; C)Estimation of tactile parameters utilized in the articulatory control of the congenitally profoundly hearing impaired people.

(4) Outline of Theory:
Virtually none available. Only some experimental data available in frequency response of the tactile system and perceptual behavior.

(5) Background Needed:
a. Sensory physiology and properties of speech.
b. Circuit theory and design.
c. Analytic signal analysis.

(6) Main References:
a. E.D. Adrian, "The Basis of Sensation, the Action of Sense Organs" Hafner Publishing Co., 1964.
b. W.L. Bulick, "Hearing Physiology and Psycho Acoustics" Oxford University Press, 1971.
c. J.L. Flanagan "Speech Analysis, Synthesis and Perception" Springer Verlag, 1972.
d. R.E. Stark (editor) "Sensory Capabilities of Hearing Impaired Children" Univ. Park Press, 1974.
e. H.M. Kagiwada "System Identification Method and Application" Addison Wesley Publ. Co., 1974.
f. R. Bogner.

Topic 16:

(1) Title - NONLINEAR FILTERING

(2) Name of Presenter: D. Williamson

(3) Problems: A)Theory of nonlinear filters (of finite dimensions) of specific structural constraints on classes of systems i.e., bilinear multiplicative noise;B)Design of specific circuits, as nonlinear phase locked loops (R.W.N.)

(4) Outline of Theory:
See papers of the presenter for the situation with regard to phase locked loops (R.W.N.).

(5) Background Needed:
a. Linear Systems linear measurements with non Gaussian noise (same except infinite dimensional filters exist for Poisson noise)
b. Linear systems, Gaussian noise non linear measurements.
c. Fokker-Planck equations (R.W.N.).

(6) Main References:
a. W.C. Lindsey, Synchronization Systems in Communications and Control, Prentice-Hall, Englewood Cliffs, N.J., 1972.
b. D. Williamson, "Improved phase-locked loop performance via nonlinear loop filters", IEEE Trans. on Comm., Vol. 27, No. 3, March 1979, pp. 542-556.
c. A.J. Viterbi, Principles of Coherent Communications, McGraw Hill, New York, 1966.
d. D. Ryter and H. Meyr, "Theory of phase tracking systems of arbitrary order: statistics of cycle slips and probability distribution of the state vector", IEEE Trans. Inf. Theory, Vol. IT-24, No. 1, Jan. 1978, pp. 1-7.

Topic 17:

(1) Title - BADLY DEFINED SYSTEMS: MODELLING AND CONTROL (MANAGEMENT)

(2) Name of Presenter: P. Young

(3) Problems:A)Interpretation of data - the scientific method re-appraised;B) Specifying nature of ambiguity, if present;C)Design of meritorious experiments;D)Control and mangement in presence of ambiguity.

(4) Outline of Theory:
System of given $\dot{x} = f(x,u,\xi)$; u control inputs : ξ noise Observations $y = g(x,u,n)$; n observation errors Given y ( ) over some interval is system fully identifiable? Is it poorly identificable? What does this mean? Can we find anything about the system if it is not excited sufficiently by u and ξ? Yes, but only partially. Will this partial knowledge mean ambiguity? Quite likely. Applications in environmental and socio-economic systems (perhaps some chemical engineering systems). The system is the description of the data. Adaptive control information content of data - what is it? How do we find the maximum amount of information of a given data set?

(5) Background Needed:
a. Control/systems/mathematics/statistics.
b. Environmental/socio-economic systems.

(6) Main References:
a. P.C. Young "A General Theory of Modelling for Badly Defined Systems" in Modelling & Control of Environmental Systems, Ed. G.K. Vansveenkiste, North Holland, 1978.

b. P.C. Young, G.H. Harbinger, R.C. Spears "Modelling Badly Defined Dynamic Systems: Some Further Thoughts" Proc. SIMSIG Simulation Conferences, Canberra, Australia, 1978.

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