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18 (19) REPORT DOCUMENTATION PAGE		2	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR TR-79-0113	2. GOVT ACCESSION NO.	3.	RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DIGITAL SYSTEM THEORY,		5. TYPE OF REPORT & PERIOD COVERED Interim	
6. PERFORMING ORG. REPORT NUMBER		8. CONTRACT OR GRANT NUMBER(s) AFOSR-78-3546	
7. AUTHOR(s) James S. Meditch	9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Electrical Engineering! University of Washington Univ. Seattle, WA 98195		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F (16) 2304 A1 (17)
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research/NM Bolling AFB, Washington, D.C. 20332		11	12. REPORT DATE February 1979
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Annual technical rept.		13. NUMBER OF PAGES 6	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		15. SECURITY CLASS. (of this report) UNCLASSIFIED	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Digital systems Inverse systems Control theory Automatic control Signal processing Vector-delay inverses			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Research progress on the development of new methods for the design of digital control systems through the use of inverse systems and their signal recovery properties is described. New results in the problem areas of vector-delay inverses and pseudoinverses are reviewed, and a novel inverse system/state observer structure for optimal control of dynamic systems is presented. The research results are applicable to both deterministic and (continued) page			

12) 9p.

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20. ABSTRACT CONTINUED.

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AFOSR-TR- 79-0113

ANNUAL TECHNICAL REPORT

for

DIGITAL SYSTEM THEORY

under

AFOSR Grant 78-3546
Air Force Office of Scientific Research (AFSC)
Bolling Air Force Base, DC 20332

Principal Investigator: Professor James S. Meditch

February 1979


DEPARTMENT OF ELECTRICAL ENGINEERING
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ABSTRACT

Research progress on the development of new methods for the design of digital control systems through the use of inverse systems and their signal recovery properties is described. New results in the problem areas of vector-delay inverses and pseudoinverses are reviewed, and a novel inverse system/state observer structure for optimal control of dynamic systems is presented. The research results are applicable to both deterministic and stochastic linear systems described in either the time or frequency domain. A major component of the research is dedicated to the development of efficient algorithms for the software implementation of vector-delay inverses and pseudoinverses. These algorithms provide tests for the existence of such inverses and then proceed to the task of realization. Theoretical studies show that the concept of vector-delay inverses includes all previous research on classical L-delay inverses as special cases. Further, the results on pseudoinverses provide means for recovering all possible unknown system inputs and/or disturbances when neither the classical nor vector-delay inverses exist.

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I. INTRODUCTION

This document constitutes the annual technical report for AFOSR Grant 78-3546, Digital System Theory. The time period covered by the report is the first year of the grant, 1 February 1978 to 31 January 1979.

II. RESEARCH OBJECTIVES

The general objective of this research program is the development of new methods for the design of digital control systems through the use of inverse systems and their signal recovery properties.

The research is focused on the three problem areas of

- (1) vector-delay inverses
- (2) pseudoinverses
- (3) inverses, observers and feedback control.

The concept of vector-delay inverses is new and encompasses all previous work on system inverses as special cases. The research on pseudoinverses is directed toward handling situations where classical and vector-delay inverses do not exist by providing partial inverses which recover as much signal information as possible. The combination of system inverses with observers under problem area (3) is intended to yield new control system and signal processing design techniques for improved performance of physical processes which must function in an uncertain and possibly hostile environment.

The specific objectives of the research program, which are motivated by practical considerations in aircraft flight test, digital flight control, pursuit/evasion in air-to-air encounters, and ground-based targeting, are:

- (A) the development of necessary and sufficient conditions for the existence of vector-delay inverses and pseudoinverses, and the formulation of efficient algorithms for their software implementation, and
- (B) the development of a control system design theory for multivariable processes that incorporates the new signal processing properties afforded by vector-delay inverses and pseudoinverses in combating the effects of uncertainty in the process' environment.

III. STATUS OF RESEARCH EFFORT

Significant progress has been made toward achieving the specific goals (A) and (B) above. The principal publication that presents the results obtained is the Ph.D. thesis of Mr. O. M. Micheloud which is presently being typed and will appear in March 1979 as a technical report entitled "Inverses for Linear Multivariable Systems." The research was supported in part by the grant under collaboration with and supervision by the principal investigator.

The results are quite complete in that both deterministic and stochastic systems are considered in the time and frequency domains. Succinctly, the contributions of the research effort can be summarized as follows:

1. The concept of vector-delay inverses is shown to include all previous research on system inverses as special cases. Two computational algorithms are provided for realization of vector-delay and minimal (inherent) vector-delay inverses, respectively, for deterministic

multivariable linear systems. In addition, a computational algorithm has been developed for systems characterized in the descriptor variable form.

2. An inverse system/state observer structure is formulated as part of an optimal control system for processes which are subject to completely unknown disturbances and/or inaccessible inputs. The structure is shown to exhibit minimal requirements for input sensors with no attendant penalty for the number of output sensors.
3. A new theoretical result has been established between the McMillan degree of a system and that of its inverse. Using this result, numerical techniques have been formulated for constructing pseudoinverses for systems whose classical or vector-delay inverses do not exist. The numerical procedures provide initially a simple test for determining which unknown inputs of the system are recoverable. The algorithms then offer the option of calculating the pseudoinverse representation in either the time (state-space) or frequency (transfer matrix) domain.
4. A theory of inverses for discrete-time stochastic linear systems is developed utilizing the methods of fixed-lag smoothing. The structure of this class of inverses is shown to be that of a multivariable finite-impulse-response (FIR) digital filter whose input is the innovations process from the Kalman filter for the original system. It is demonstrated theoretically that these inverses always exist and are stable under the same conditions that guarantee existence and stability, respectively, of the Kalman filter for the original

system. Synthesis of these inverses is extremely simple utilizing existing microprocessor technology.

IV. PUBLICATIONS IN TECHNICAL JOURNALS

The following papers resulting from this research program have been accepted for publication.

1. J. S. Meditch, "Stable continuous-time fixed-lag smoothers for stationary random processes," IEEE Trans. Automat. Contr., vol. AC-24, no. 2, Apr. 1979, to appear.
2. _____, "On the representation of optimal fixed-lag smoothers for continuous-time random processes," Intl. J. Contr., 1979, to appear.

In addition, the following two papers are in preparation and will be submitted to the journals indicated.

3. J. S. Meditch and O. M. Micheloud, "Inherent vector delay and the realization of partial inverses for multivariable linear systems," Automatica.
4. O. M. Micheloud and J. S. Meditch, "Multivariable vector-delay inverses in the frequency domain," IEEE Trans. Automat. Contr.

V. PROFESSIONAL PERSONNEL ASSOCIATED WITH THE RESEARCH EFFORT

The personnel involved with this research program during the year were Professor James S. Meditch, Chairman, Department of Electrical Engineering, who is the Principal Investigator, and Mr. O. M. Micheloud, a pre-doctoral research assistant in the Department of Electrical Engineering.

As noted in Section III, Mr. Micheloud's doctoral thesis is presently being typed. He will conclude his work under the grant at the end of

the 1979 Winter Quarter, March 15, 1979, and receive the Ph.D. degree in electrical engineering from the University of Washington in June 1979. The title of his thesis is "Inverses for Linear Multivariable Systems."

VI. INTERACTIONS

During the year, the following technical papers resulting from this research program were presented by the principal investigator and appear in conference proceedings as noted.

1. J. S. Meditch, "Inverses for discrete-time stochastic linear systems," Proc. 1978 Conf. on Info. Sci. and Systems, Baltimore, Md., Mar. 1978, pp. 124-128.
2. V. H. Syed and J. S. Meditch, "The optimal tracking problem for non-stationary stochastic processes," Proc. 7th Triennial Congr. of Intl. Fed. of Automat. Contr., Helsinki, Finland, June 1978, pp. 2049-2056.
3. J. S. Meditch, "On the representation of optimal fixed-lag smoothers for continuous-time random processes," Proc. 16th Allerton Conf. on Comm., Contr. and Comput., Univ. of Ill., Urbana, Ill., Oct. 1978, in press.
4. V. H. Syed and J. S. Meditch, "Minimum-variance controllers for feedback stochastic systems," Proc. 1978 Joint Automat. Contr. Conf., Philadelphia, Pa., Oct. 1978, pp. 649-660.