FINAL REPORT

Advanced Theoretical and Experimental Studies in Automatic Control and Information Systems

NASA GRANTS NSG 354 and NGL 05-003-016

Principal Investigators
C. A. Desoer/E. Polak/L. A. Zadeh

ELECTRONICS RESEARCH LABORATORY

College of Engineering
University of California, Berkeley
94720
Over a ten-year period a sequence of projects were undertaken in the following areas: (i) mathematical programming problems for large system and infinite-dimensional spaces [9,19,21,28], (ii) Bounded-input bounded-output stability, (iii) non-parametric approximations [43,62] and (iv) differential games [56,92,96]. Since the time that these projects were completed all these areas, with the exception of (iii), have attracted a great deal of effort in the profession.

Looking over our list of publications for the last ten years, we see that we have made a number of important contributions to the theory of optimal control, to game theory, to systems theory and to optimization. To review a sample of the papers which were published, [4,12] were the first papers in the literature to develop maximum principle type conditions for discrete optimal control theory, [27] has been recognized as a classical paper in the theory of general optimality conditions, [36,38] are always referenced in papers dealing with vector optimization problems, and are often referred to in the literature on differential games. References [39,40] are further contributions to game theory. Reference [38] presented a widely recognized method for linear system identification; [23] and [46] were other contributions to linear system theory. Over the years we have developed a large number of new and highly efficient optimization algorithms [51,57,60,81,88,97,98,99,105,106, 108,109,110,120,123] and we have developed a series of very powerful tools to the analysis and synthesis of optimization algorithms [76,83,87, 93,99,103,104,108,128,130]. All in all, the last five years were a highly successful period in our research.

A major part of the effort was put on the problem of stability of feedback systems. For nonlinear systems; [7] is a classic reference on
the Popov criterion, for $L^p$-stability, [65] and [122] are basic references.
For linear systems [52, 78, 100, 101, 107, 119] represent a succession of
increasingly general and sophisticated results which are widely quoted.
The best known result concerning the Nyquist graphical test is in [113].
An overview of all this work on stability together with the work of many
others is to be found in [131]. Reference [80] tackles the problem of
optimizing characteristics, a technique taken up later by Peikari.
Singular perturbation were considered in [68, 89, 90, 121]. A basic
misconception in minimal realization was resolved in [22].

During the past ten years, the main thrust of our research was
directed at the development of approximate techniques for dealing with
the system that are too complex or too ill-defined to be amenable to
analysis by conventional quantitation methods.

To this end, the notion of a fuzzy algorithm was introduced in [55].
In [69], a framework for the analysis of fuzzy systems was set up and in
[94] the problem of decision-making in a fuzzy environment was formulated.
This work culminated in the development of the so-called linguistic
approach [124], in which words or sentences rather than numbers are
employed to describe phenomena which are not susceptible of quantitative
characterization. This approach shows considerable promise as an effective
tool for the analysis of large scale systems.
III. LIST OF REPORTS AND PAPERS


74. J.P. Jacob and E. Polak, "On a class of pursuit-evasion problems," 
IEEE Trans. on Automatic Control, Vol. AC-12, No. 6, pp. 752-755, 
December 1967.

75. E. Polak, "Computational methods in discrete optimal control and 
nonlinear programming—a unified approach," Memorandum No. ERL-M261, 
February 1969 To be published under the title Notes on Computa-

76. E. Polak, "On the convergence of optimization algorithms," Revue 
Francaise d’Informatique et de Recherche Operationelle, Serie Rouge 
No. 16, pp. 17-34, 1969.

77. E. Polak and G. Ribiere, "Note sur la convergence de methods de 

78. C. A. Desoer and M. Y. Wu, "Input-output properties of multiple-input 
multiple-output discrete systems: Part I," Journal of the Franklin 
the Franklin Institute, Vol. 290, No. 2, August 1970, pp. 85-101, 
(also Memorandum No. ERL-M262, June 1969).

79. E. Messerli, "A hybrid conjugate gradient steepest descent algorithms 
for unconstrained minimization," submitted to the Journal of Optimi-
zation Theory and Applications.

80. C. A. Desoer and M. K. Inan, "Optimization of nonlinear characteris-
tics," presented at the 7th Annual Allerton Conference on Computer 
and System Theory, October 8-10, 1969, Allerton, Illinois, pp. 166-
168. Journal of Mathematical Analysis and Applications, Vol. 33, 
No. 3, pp. 574-604, March 1971, (also Memorandum No. ERL-M267, 

81. G. Meyer and E. Polak, "A decomposition algorithm for solving a class 
of optimal control problems," Published in the Journal of Mathematical 

82. C. A. Desoer and M. Y. Wu, "Input-output properties of linear discrete 
systems," presented at the 7th Annual Allerton Conference on Computer 

83. G. Meyer and E. Polak, "Abstract models for the synthesis of optimi-
zation algorithms," SIAM Journal on Control, Vol. 9, No. 4, November 

84. M. Y. Wu and C. A. Desoer, "Input output properties of nonlinear 
discrete systems," Proc. 7th Allerton Conference on Computer and 

85. M. K. Inan, "On the perturbational sensitivity of solutions to nonlinear 
differential equations," submitted to the SIAM Journal on Control, (also 
86. A. I. Cohen, "Rate of convergence of several conjugate gradient algo-
rithms," SIAM Journal of Numerical Analysis, Vol. 9, No. 2, pp. 248-
259, June 1972. Also presented at the Fifth Annual Princeton Confer-
ence on Information Sciences and Systems, March 25-26, 1971 in Princeton,
New Jersey.

87. G. Meyer and E. Polak, "Abstract models for the synthesis of efficient
optimization algorithms," presented at the 1970 JACC Invited Session
on Computational Methods, South Carolina, June 1970.

88. E. Polak, "On the implementation of conceptual algorithms," presented
at the Symposium on Nonlinear Programming, Madison, Wisconsin, May
3-6, 1970.

89. C. A. Desoer, "Slowly varying discrete system \( x_{i+1} = A_i x_i \)," Electronics

90. C. A. Desoer, "Singular perturbation and bounded-input bounded-state
stability," Electronics Letters, Vol. 6, No. 16, pp. 496-497, August
1970.

91. C. A. Desoer and F. L. Lam, "Stability of linear time-invariant dis-
crete systems," Proc. of the IEEE, Vol. 58, No. 11, pp. 1841-1843,
November 1970.

92. P. P. Varaiya, "N-person non-zero sum differential games with linear
dynamics," SIAM Journal on Control, Vol. 8, No. 4, pp. 441-449,
November 1970.

93. E. Polak, "On the use of models in the synthesis of optimization algo-
rithms," presented at the International Summer School on Mathematical
in Mathematical Models of Action and Reaction, H. W. Kunh and G. P.

Management Science, Vol. 17, No. 4, December, 1970, pp. B-141-

95. L. A. Zadeh and J. P. Jacob, "Fuzzy systems, programming and control,
presented at the 1970 Kyoto International Conference on Circuit and
System Theory, September 1970, Kyoto, Japan.

96. P. P. Varaiya, "Differential games," presented at the Sixth Berkeley
Symposium on Mathematical Statistics and Probability, June 22 - July
17, 1970, in Berkeley, California and appeared in the Proceedings,

97. R. Klessig and E. Polak, "Efficient implementation of the Polak-Ribière
conjugate gradient algorithm," SIAM Journal on Control, Vol. 10, no. 3,


120. E. Polak, "A globally converging secant method, with applications to boundary value problems," to be issued in the March 1974 issue of the SIAM Journal on Numerical Analysis.


130. L. J. Williamson and E. Polak, "Relaxed controls and the convergence of optimal control algorithms," submitted to the SIAM Journal on Control.