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RESEARCH ON OPTIMIZATION-BASED COMPUTER-AIDED DESIGN OF
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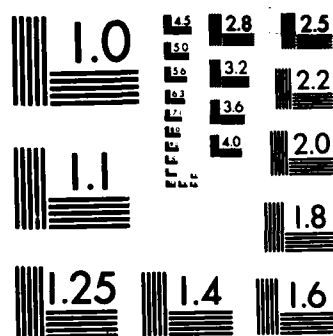
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RESEARCH ON OPTIMIZATION-BASED COMPUTER-AIDED DESIGN OF CONTROL SYSTEMS

FINAL REPORT

by

Elijah Polak

for

Office of Naval Research

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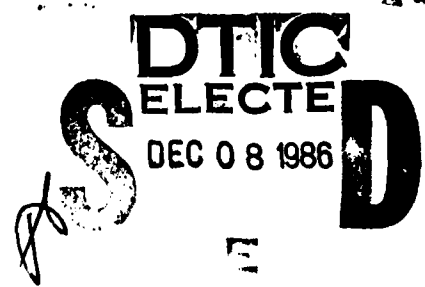
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The research covered by this report was aimed at advancing the state of the art of optimization-based design of control systems. To this end, research was carried out in three areas: (i) the development of a theory of nondifferentiable optimization algorithms for the solution problems with max type inequality constraints, (ii) the exploration of efficient design parametrization and initialization techniques in optimization-based control system design, and finally, (iii) the development of interactive software for optimization-based control system design. As a result of this research, two students will receive their Ph.D. degrees in November, 1986, two students are halfway through their doctoral research projects, and our interactive optimization-based design system DELIGHT.MIMO was completed. It is currently being installed in alpha sites for testing and evaluation. The Michelson Laboratory in China Lake is one such test site.				
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The research covered by this report was aimed at advancing the state of the art of optimization-based design of control systems. To this end, research was carried out in three areas: (i) the development of a theory of nondifferentiable optimization algorithms for the solution problems with max type inequality constraints, (ii) the exploration of efficient design parametrization and initialization techniques in optimization-based control system design, and finally, (iii) the development of interactive software for optimization-based control system design.

(i) Since 1984, we have been working on a constructive theory of nondifferentiable optimization algorithms. The purpose of this theory is to elucidate the principles of nondifferentiable optimization algorithm construction. A first version of this theory appeared in [2], it was further refined in [3] and it will appear in final form in SIAM Review in February 1987. The SIAM Review is probably the only publication where one can publish a paper dealing with a new and complex theory in an expository fashion. Our manuscript is well over 100 pages long and, hopefully, sufficiently self contained to open up our algorithms and algorithm construction tools to a wide audience. The most important aspects of our work are: (a) the discovery of a mechanism for generating continuous search direction functions which lead to extremely well behaved optimization algorithms, and (b) the discovery that the generation of nondifferentiable optimization algorithms is "elastic" in the sense that one can generate endless families of nondifferentiable optimization algorithms. There are two important consequences to this elasticity, the first is that it has enabled us to construct new, quadratically convergent algorithms for semi-infinite optimization (manuscript in preparation) and the second is that it opened up new avenues for scaling algorithms so as to

enhance their behavior. The exploration of the latter has become the topic of a doctoral dissertation.

(ii) Our work on efficient parametrizations techniques for use in optimization-based control system design was reported in [1] and [4] to [15].

In [1, 12, 14] we presented our work on worst case design in the presence of structured and unstructured uncertainty. Our major contribution in this area is a computational complexity reduction scheme.

In [6] and [7] we showed that it is possible to define an uncertainty identification scheme which can be used to produce information for redesigning the control system under worst case assumptions. We showed that this new approach to adaptive control results in a stable system whose performance improves with time, as the system uncertainty is reduced.

In [15] and a follow up paper, in preparation, we show that the well known, so called Zames' Q -parametrization of stabilizing compensators leads to transcriptions of control system design problems with both time *frequency domain and time domain* constraints, specified in terms of bounds on H_∞ norms on transfer function matrices (in frequency domain) or impulse response matrices (in time domain) into convex, semi-infinite optimization problems. The effect of Q -parametrization induced convexity is to remove the undesirable effects of local minima which result from other types of parametrizations. We showed that these constrained H_∞ problems can be solved by our new semi-infinite optimization algorithms and presented numerical results for a couple of sample problems. Thus our algorithms considerably advance the possibilities of

design using H_∞ concepts, as well as control system design with respect to other norms. We are currently exploring techniques for extending these results for the design of *finite dimensional* stabilizing controllers for large, flexible structures.

Our research on optimal control algorithms, which can be used for solving optimal control problems with either ODE or PDE type dynamics, control and state space constraints, was presented in [11]. Finally, our work on control system design formulation as a semi-infinite optimization problem and on simulation techniques for optimization-based control system design were presented in [4, 5, 8, 13]. Finally, [9, 10] present some preliminary results on algorithms dealing with collision avoidance problems.

(iii) Our interactive, optimization-based computer-aided multivariable control system design package, DELIGHT.MIMO, has recently been completed and is being placed in alpha sites for testing and evaluation. These include the Michelson Laboratory, the General Electric Co. Research Center in Schenectady, the Hewlett Packard Co. and several university sites. Hopefully, it will simplify considerably the use in industry of optimization-based computer-aided control system design tools. An important aspect of this package is a very friendly graphical user interface which makes the definition of system interconnections and transcription of a design problem into an optimization problem a simple, error free task. In addition, by powerful windowing techniques, it allows the user to examine simultaneously various systems outputs as well as their variations produced by user dictated design parameter changes.

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