

# REPORT DOCUMENTATION PAGE

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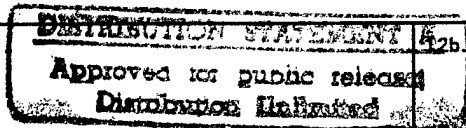
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13. ABSTRACT (Maximum 200 words)  Several research topics related to the delta-operator have been studied. Firstly, we are completing our research on the delta-operator based efficient stability tests by tying all loose ends and presenting the results in various coherent ways. Secondly, a delta-operator based least squares lattice algorithm has been developed. The new algorithm is computationally efficient, and has better numerical properties than the existing ones. Thirdly, more results have been obtained in the least squares method using the "generalized delta operator". In one of these new results, a computationally efficient algorithm using the delta operator has been developed to estimate continuous-time autoregressive process parameters from discrete-time data. Other topics such as blind equalization have also been studied and further results obtained.
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OFFICE OF NAVAL RESEARCH  
ANNUAL PROJECT REPORT

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CONTRACT: N00014-96-1-0241  
TITLE: High Speed, Numerically Superior Signal Processing Algorithms Using  
QRD & Delta Operator  
PI: Dr. H. (Howard) Fan, University of Cincinnati  
PERIOD: 1 October 1996 through 30 Sept. 1997

This period is the second annum under this new grant. Our efforts are focused on the following activities:

1. Continue to study and disseminate the delta-operator based stability test algorithms, due to the importance of this subject. We have revised and published some previously submitted journal papers (B2), and have published a conference paper (I2). We are completing this important subject in many details, and are preparing to write a book on it. The PI also organized an invited session on the delta operator in systems, control, and signal processing for the coming IEEE Conference on Decision and Control to be held in San Diego in December 1997.
2. Our study shows that the delta operator based signal processing algorithms seem to give comparable numerical behavior as the QRD based algorithms, whereas their combination does not seem to give any further improvement in numerical behavior. We are currently studying this phenomenon, in trying to understand why this is the case. Meanwhile, we have improved our previous results on delta-operator Levinson and Schur algorithms to have achieved yet much better results than before (see publication H2). Recently we have also developed a delta least squares lattice algorithm. This algorithm has very high computational efficiency (at the order of  $O(N)$  where  $N$  is the order of the lattice filter) and better numerical accuracy than the traditional least squares lattice algorithm under fast sampling. We have submitted a conference paper to ICASSP '98, and will be submitting a journal paper shortly. During this period we also published a conference paper on our results about the modified normalized lattice and its limit as the sampling frequency approaches infinity (I3). This result had been reported last year.
3. The cooperative research on the "generalized delta operator" with the Swedish researchers led by Prof. Söderström turns out to be quite "profitable". We concentrate our study on identification of continuous-time ARX model parameters using discrete-time data and either the delta operator or the generalized delta operator. Not only have we published our first result using the least squares approach in the journal form (B3), we also have obtained further interesting results in terms of bias compensation and ways of coping with additive noise. Some of the new results have been presented recently in a conference (I1). We have also submitted a conference paper to ICASSP'98, and submitted a journal paper as well (A3). The results with additive noise will also be submitted and published in the near future.
4. Blind Equalization. This work is a continuation of the last year's work which was jointly supported by the AASERT program under Grant N00014-93-1-1032 (expired). We have constructed a family of new cost functions which work at least as well as the well known constant modulus algorithm (CMA), also known as the Godard-2 algorithm, but may even potentially be better than the CMA. We have submitted two journal papers (A1 and A2) and presented one more conference paper (I4). We have also filed a provisional patent application on this technique (F1). Recently we have developed a stochastic Newton-like algorithm for blind equalization. The new algorithm applies to many cost functions including the CMA and our own, and converges much faster than the existing algorithms. The computational complexity is  $O(N^2)$ . We have submitted a conference paper to ICASSP'98. Currently we are working on its fast

implementation (QRD-LSL-like) which will have a computational complexity of only  $O(N)$ , and will be filing another patent application on these results.

5. Continue to work on other aspects which were initiated before. One of them is the robustness issue in our previous work on linear time-varying system modelling using wavelets. We have shown that our previous approach, which was reported previously, is robust to narrow band noise or impulsive noise. We presented an invited paper at a recent conference (H1) and have also submitted a journal paper on this subject (A4). We have also overseen the publication processes to completion for the papers (B1) and (B4).

**OFFICE OF NAVAL RESEARCH  
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT  
for  
1 October 1996 through 30 Sept. 1997**

**Contract/Grant Number:** N00014-96-1-0241

**Contract/Grant Title:** High Speed, Numerically Superior Signal Processing Algorithms Using QRD and Delta Operator

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- a. Number of Papers Submitted to Refereed Journals but not yet published:   4
- b. Number of Papers Published in Refereed Journals:     4
- c. Number of Books or Chapters Submitted but not yet Published:     0
- d. Number of Books or Chapters Published:     1
- e. Number of Printed Technical Reports & Non-Refereed Papers:   0
- f. Number of Patents Filed:   1
- g. Number of Patents Granted:   0
- h. Number of Invited Presentations at Workshops or Prof. Society Meetings:     2
- i. Number of Presentations at Workshops or Prof. Society Meetings:     4
- j. Honors/Awards/Prizes for Contract/Grant Employees:     0
- k. Total number of Graduate Students and Post-Docs Supported at least 25%,  
on this contract/grant:  
                                  Grad Students   3        and Post Docs   0

How many of each are females or minorities? (These 6 numbers are for ONR's EEO/Minority Reports: minorities include Blacks, Aleuts Amindians, etc. and those of Hispanic or Asian extraction/nationality. These Asians are singled out to facilitate meeting the varying report semantics re "under-represented").

[	Grad Student Female	<u>    </u>
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]	Post-Doc Female	<u>    </u>
]	[	
]	Post-Doc Minority	<u>    </u>
]	[	
]	Post-Doc Asian e/n	<u>    </u>

## A. PAPERS SUBMITTED TO REFEREED JOURNALS

1. V. Shtrom and H. Fan, "A new class of cost functions in blind equalization," IEEE Trans. on Signal Processing, in review..
2. V. Shtrom and H. Fan, "Analysis of the effects of additive white Gaussian noise on two blind equalization algorithms," IEEE Trans. on Information Theory, in review.
3. H. Fan, T. Söderström, M. Mossberg, B. Carlsson, and Y. Zou, "Estimation of continuous-time AR process parameters from discrete-time data," IEEE Trans. on Signal Processing, in review.
4. M. Doroslovacki, H. Fan, and L. Yao, "Wavelet-based identification of linear discrete-time systems: Robustness issue," Automatica, in review..

## B. PAPERS PUBLISHED IN REFEREED JOURNALS

1. H. Fan, "A structural view of asymptotic convergence speed of adaptive IIR filtering algorithms – Part II: Finite precision implementation," IEEE Trans. on Signal Processing, vol. 45, no. 6, pp. 1458-1472, June 1997.
2. H. Fan, "Efficient zero location tests for delta-operator based polynomials," IEEE Trans. on Automatic Control, vol. 42, no. 5, pp. 722-727, May 1997.
3. T. Söderström, H. Fan, B. Carlsson, and S. Bigi, "Least-squares parameter estimation of continuous-time ARX models from discrete-time data," IEEE Trans. on Automatic Control, vol. 42, no. 5, pp. 659-673, May 1997.
4. H. Fan, "An efficient order recursive algorithm with a lattice structure for estimating continuous-time AR process parameters," Automatica, vol. 33, no. 3, pp. 305-317, March 1997.

## D. BOOKS OR CHAPTERS PUBLISHED

The following paper

H. Fan and X. Liu, "Delta Levinson and Schur type RLS algorithms for adaptive signal processing," IEEE Trans. Signal Processing, vol. 42, no. 7, pp. 1629-1639, July 1994

has been selected to be included in the following edited book:

High Performance VLSI Signal Processing – Innovative Architectures and Algorithms, K.J.R. Liu and K. Yao, eds., IEEE Press, 1997.

## F. PATENTS FILED

1. V. Shtrom and H. Fan, "Methods and apparatus useful in blind equalization," Provisional patent application filed by the University of Cincinnati Patent Office, April 1997.

## H. INVITED PRESENTATIONS AT PROFESSIONAL SOCIETY MEETINGS

1. M. Doroslovacki and H. Fan, "Wavelet-based identification of linear discrete-time systems," Proc. 11th IFAC Symposium on Syst. Id., vol. 1, pp. 9-14, Kitakyushu, Japan, July 1997.
2. H. Fan, "Improved delta Levinson and Schur type RLS algorithms," Proc. 34th Allerton Conf. on Comm., Control, and Computing, Monticello, IL, Oct. 1996.

## I. PRESENTATIONS AT PROFESSIONAL SOCIETY MEETINGS

1. T. Söderström, H. Fan, M. Mossberg, and B. Carlsson, "A bias-compensation scheme for estimating continuous-time AR process parameters," Proc. 11th IFAC Symposium on Syst. Id., vol. 3, pp. 1337-1342, Kitakyushu, Japan, July 1997.
2. H. Fan, "Delta-operator based efficient stability tests," Proc. 1997 American Control Conference, vol. 4, pp. 2508-2512, Albuquerque, NM, June 1997.
3. P. De and H. Fan, "A modified normalized lattice adaptive filter for fast sampling," Proc. Intl. Conf. on Acoust., Speech, Signal Processing, vol. 3, pp. 1941-1944, Munich, Germany, April 1997.
4. V. Shtrom and H. Fan, "A refined class of cost functions in blind equalization," Proc. Intl. Conf. on Acoust., Speech, Signal Processing, vol. 3, pp. 2273-2276, Munich, Germany, April 1997.

## K. GRADUATE STUDENTS SUPPORTED UNDER THE CRP FOR THIS PERIOD

1. P. De, Ph.D. candidate
2. G. Yan, Ph.D. candidate (partially supported)
3. X. Li, Ph.D. candidate (partially supported)