REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 8/2/99	3. REPORT TYPE AND DATES COVERED Final 06/01/97 through 06/30/99

4. TITLE AND SUBTITLE

DISTRIBUTED SENSOR FUSION BASED ON STATISTICAL INFERENCE

5. FUNDING NUMBERS

CONTRACT
N00014-97-1-0917

6. AUTHOR(S)

RAMANARAYANAN VISWANATHAN

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

DEPARTMENT OF ELECTRICAL ENGINEERING
SOUTHERN ILLINOIS UNIVERSITY
at CARBONDALE
CARBONDALE IL. 62901-6603

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

OFFICE OF NAVAL RESEARCH
BAALLSTON TOWER ONE
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

In the twenty-five month period between June 1997 and June 1999 we have looked into three problems related to data fusion from multiple sensors. The first deals with the distributed constant false alarm rate radar target detection, the second deals with order statistics based diversity combining for fading channels, and the last examines a rank based test M-ary detection problem.

14. SUBJECT TERMS

DISTRIBUTED CFAR TESTS, RANK TESTS, DIVERSITY COMBINING

15. NUMBER OF PAGES 3

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

19990806 008

Final Technical Report

Contract – N00014-97-1-0917

Title: Distributed Sensor Fusion
        Based on Statistical Inference

PI: Ramanarayanan Viswanathan

DTIC QUALITY INSPECTED 4

Final Report on the Contract- N00014-97-1-0917

Title   **Distributed Sensor Fusion Based on Statistical Inference**

PI   **Ramanarayanan Viswanathan**

In the twenty-five month period between June 1997 and June1999 we have looked into three problems related to data fusion from multiple sensors. The first deals with the distributed constant false alarm rate radar target detection, the second deals with order statistics based diversity combining for fading channels, and the last examines a rank based test for M-ary detection problem.

1. Distributed CFAR Tests

We have evaluated the performances of several distributed CFAR tests operating in different background clutter conditions [1-5]. The analysis considers the detection of Rayleigh target in various clutters with the possibility of varying clutter power levels in the test cells of distributed radars. Numerical results studied for a two radar system show how the false alarm rate of the maximum order statistic (MOS) test changes with differences in the clutter power levels of the test cells. The analysis for the detection of Rayleigh target in Rayleigh clutter indicates that, with differing clutter cells' power levels, the OR fusion rule can be quite competitive with the new normalized test statistic (NTS). However, for the detection of Rayleigh target in Weibull or K- distributed clutter, the results show that NTS outperforms both the OR and the AND rules under the condition of large signal to clutter power ratio and moderate shape parameter values.

2. Order Statistics Based Diversity Combining

We have considered a new order statistics based diversity combining scheme (OSDC) for combining a set of independently fading signal amplitudes [6]. The traditional combining schemes employed are the equal gain combining (EGC), maximal ratio combining (MRC), and selection combining (SC). Though MRC is the optimal diversity combiner, it is difficult to implement in a multipath fading channel, as the receiver complexity for MRC is directly proportional to the number of resolvable paths. Another scheme examined in the recent literature is called the second order selection combining (SC2), which coherently combines the two signals which have the largest signal-to-noise ratios. The proposed OSDC orders all the received signal amplitudes and uses only the two strongest signals in the combining process. The decision as to whether to use only the strongest or both the strongest and the next strongest is made depending on the relative strengths of these two highest order statistics. Signal-to-noise performance of the new scheme is compared with that of the other schemes such as, SC, MRC, EGC, and SC2, for three channels, namely Rayleigh, Nakagami, and exponential. The results show that OSDC performs as well as SC2. Both perform much better than the simple selection scheme, SC. The complexities of implementation of SC2 and OSDC are comparable. If one accounts for measurement errors, then a sensitivity analysis would be needed to ascertain the robustness in performances of SC2 and OSDC.

3. Rank Based Tests for M-ary Detection

We examined a rank order based test for a general M-ary communication problem, which is stated as follows: Given M groups of L samples each, the problem is to identify which unique group of L samples have come from the signal hypothesis. The optimal likelihood ratio test that minimizes the probability of incorrect classification can be constructed if the joint distribution of these ML samples is completely known. However, in many cases, the distribution is either unknown or only known partially. Therefore, suboptimal tests, such as tests based on rank orders, can be considered. By considering the observations as a matrix of M rows with L columns, a rank matrix is created by rank ordering these observations and then replacing the samples with their corresponding ranks. Then a *Rank Sum Test* declares the row with the maximum rank sum as the row corresponding to the signal hypothesis. Since ranking ML samples might take considerable amount of time, a *Reduced Rank Sum Test* (RRST) rank orders the samples in each column separately into values of 1 through M, and then picks the row with the maximum rank sum. A variation of the RRST is to create a value matrix where the (i,j) element of the value matrix is either equal to the (i,j) element of the rank matrix, if the rank exceeds a threshold $M-p+1$, or is equal to zero. The *Modified Rank Test* (MRT) then picks the row with the maximum sum of values. If $p=1$, the MRT retains only the maximum rank of M in each column and assigns zero values to the others. In other words, independently for each column, the row with the largest rank is decided as the signal row. Therefore, for $p=1$, MRT can be thought of as a majority logic combining of the decisions made in each column. For other values of p, MRT can be thought of as combining decisions, when decisions are presented with confidence weights [7]. Another variation of MRT is obtained by first sorting out elements in each row according to their values before performing the reduced ranking and clipping operations. We call such a procedure as row sorted MRT [8]. What row sorting does is to produce comparison of weakest signal against weakest interference (plus noise), comparison of the next weakest signal against the next weakest interference, and so on. Through simulation studies we have found that row sorting produces significant reduction in error rates in a number of constant signal-in-noise detection problems involving Gaussian, Laplace and exponential distributions. Certainly, for low p values, the row sorting reduces the error rate of simple MRT by an order of magnitude [8].

Encouraged by these results we examined the applicability of MRT to diversity combining of antenna array signals in a wireless DS/CDMA system. The performances of equal gain combining (EGC), likelihood ratio test (LRT) and the MRT were evaluated using simulation studies [9,10]. The results indicate that, under certain assumptions on the multiple access interference statistics, the probability of error of MRT(row sorted) is lower than that of EGC, if a few high power interfering users are present along with a low power user of interest. If there are a moderately large number of users and if the received powers of all the users are nearly the same, then EGC outperforms MRT. In fact, under this condition, the performance of EGC is close to that of the optimal likelihood ratio test.

Publications

1. C.H. Gowda, M.K. Uner, P.K. Varshney and R. Viswanathan, "Distributed CFAR Target Detection," the *Journal of Franklin Institute*, 1999, pp. 257-267.

2. C.H. Gowda and R. Viswanathan, "Performances of Distributed CFAR Tests in Nonhomogeneous Background," *Proceedings of the National Radar Conference*, Syracuse, NY., 1997, pp. 36-41.

3. C.H. Gowda and R. Viswanathan, "Distributed Detection of Rayleigh Target in Weibull Clutter," *Proceedings of CISS*, Department of Electrical Engineering, Princeton University, Princeton, NJ., 1998, pp. 85-90.

4. C.H. Gowda and R. Viswanathan, "Distributed Detection of Rayleigh Target in K-Distributed Clutter," *Proceedings of SPIE*, Sensor Fusion: Architectures, Algorithms, and Applications II, Orlando, FL, 1998, pp. 175-185.

5. C.H. Gowda and R. Viswanathan, "Performance of Distributed CFAR Tests Under Various Clutter Amplitudes," to appear, *IEEE Transactions on AES*, July 1999.

6. S. Gollakotta and R. Viswanathan, "Order Statistics Based Diversity Combining for Fading Channels," in the proceedings of the *Thirty-second Asilomar Conference on Signals, Systems, and Computers*, Asilomar, CA, Nov., 1998, pp. 578-582.

7. V. Annampedu and R. Viswanathan, "A Rank Order Test for M-ary Detection," *Proceedings of the Conference on Information Sciences and Systems*, Department of Electrical Engineering, Johns Hopkins University, March 1997, pp. 819-824.

8. V. Annampedu, V. Roganov, and R. Viswanathan, "Two Rank Order Tests for M-ary Detection," revised version submitted to *IEEE Transactions on Information Theory*, July 1999.

9. C.H. Gowda, V. Annampedu, and R. Viswanathan, "Diversity Combining in Antenna Array Base Station Receiver for DS/CDMA,"*IEEE Communications Letters*, July 1998, pp. 180-182.

10. C.H. Gowda, V. Annampedu, and R. Viswanathan, "Diversity Combining in Antenna Array Base Station Receiver for DS/CDMA," Conference proceedings, *International Conference on Communications*, Atlanta, GA, June 1998, S38-6.