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Distributed Sensing and Processing: A Graphical Model Approach

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REPORT NUMBER

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11. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12 a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

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13. ABSTRACT (Maximum 200 words)

The cost of direct computation of the detection error probabilities in a sensor network -- e.g., the probability of false alarm, the probability of a miss, or the average probability of error -- is combinatorial with the number of sensors. This limits the design of the optimal detector to networks with a very small number of sensors. Our work developed a simple very accurate large-deviation method to compute these probabilities of error based on the saddle-point approximation. The saddle-point aproximation can be used with networks with an arbitrary (small or large) number of sensors. We used it to resolve three major network issues: design the optimal distributed sensor network detectors in the Neyman-Pearson and Bayes criteria; establish the performance tradeoffs among different network parameters like the signal-to-noise ratio, the number of network sensors, and the number of bits quantizing the local network (soft-) decisions; and the design of the optimal sensor network topology. Our methods apply to generic parallel and distributed (web like) architectures. We showed that Ramanujan graph toplogies maximize the convergence rate of distributed detection consensus algorithms, improving over three orders of magnitude over the speed of convergence of structured networks (e.g., nearest neighbor type networks) and close to two orders of magnitude over small world type network designs.

14. SUBJECT TERMS
Ramanujan graphs, sensor network topology, sensor network tradeoffs, consensus algorithm sensor networks, integrated sensing processing, distributed detection, saddle-point approximation

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Enclosure 1

REPORT DOCUMENTATION PAGE (SF298)
(Continuation Sheet)

Foreword

We considered three main issues in distributed detection in sensor networks: 1) how to compute the performance of the detector, e.g., the average probability of error, when the network has an arbitrary (large or small) number of sensors; 2) how to quantify network parameter tradeoffs like signal-to-noise ratio, number of active sensors in the network, or number of bits per local decision at each sensor; and 3) how to design the topology of the network to minimize the number of iterations needed to achieve convergence with a distributed consensus algorithm. We developed a large deviation method, a saddlepoint based approximation, to compute the probability of error for sensor networks with arbitrary number of sensors. We used this saddlepoint based approach to study the network parameter tradeoffs, in particular, what is the incremental SNR needed to reduce the number of sensors or the number of bits quantizing the local decisions at each sensor and achieve the same overall performance. Regarding network topology, we studied the design of the topology of a distributed sensor network, where the goal is to optimize the rate of convergence of a distributed inference consensus algorithm. We showed that this problem is equivalent to a spectral graph design problem: optimizing the rate of convergence is equivalent to designing the graph that maximizes a given eigenratio parameter, namely, the ratio of the algebraic connectivity, i.e., the second smallest eigenvalue of the graph Laplacian, to the largest eigenvalue of the graph Laplacian. We showed that Ramanujan graphs, for which there are explicit algebraic constructions, have large eigenratios, converging much faster than structured graphs (like nearest neighbor communication graphs), Watts-Sytrogatz small-world graphs, or Erdos-Renyi random graphs. Finally, because the constructions available for Ramanujan graphs restrict the number of graph nodes, we proposed a new class of graphs that can be constructed with an arbitrary number of nodes and whose convergence properties approach those of Ramanujan graphs.

Statement of Problem

The potential for large-scale sensor networks is attracting great interest in many applications in recent years due to emerging technological advancements. Increasing levels of electronics and RF circuits integration as well as the development of robust signal processing algorithms lend themselves to the deployment of affordable, yet reliable sensing systems, which are envisioned as networks of autonomous densely distributed sensor nodes. Individually, each sensor node may not accomplish much, but, working cooperatively, they have, for example, the potential to monitor large areas, detect the presence or absence of targets, or track moving objects.

The design and analysis of sensor networks for detection applications has received considerable attention in the past decade. Our work addressed three issues in distributed inference in large sensor networks: develop a method that is computationally feasible and accurate to compute the detection performance associated with a sensor network, namely the probability of error; study tradeoffs among network parameters for efficient utilization of the network resources; and design the topology of the netwrk, i.e., with which sensors should each sensor communicate with to minimize communication among sensors (and so, minimize power consumption, bandwith utilization, and channel crowding) in distributed inference algorithms.

Summary of Results

Network detector: Design and Performance Evaluation
A major difficulty usually encountered in sensor network applications is the high computational cost associated with evaluating the detection error probabilities of the network---a combinatorial problem in the number N of

sensors---which can be extremely high when the number of sensors is large. Direct evaluation of these probabilities is possible only for rather small networks. Our work has developed a computationally fast and accurate methodology to evaluate the error, detection, and false alarm probabilities for networks of arbitrary size---small, medium, or large number of sensors. Our method is based on large deviation theory approximations to these probabilities, in particular, the saddlepoint approximation.

We have illustrated the saddlepoint based methodology by considering a binary hypothesis detection problem in which the environment assumes one of two possible states (e.g., a target is present or absent). We focused on a parallel network architecture in which the sensors make local decisions based on their own measurements and then deliver these local decisions to a fusion center. The local measurements are quantized to b bits, so the local detectors can be thought of as b-bit local quantizers.

In this particular architecture, called parallel fusion, there is no communication among the local sensors and the fusion center does not sense the physical phenomenon. Fundamental results on distributed detection with a parallel architecture date back to the early work of Tenney and Sandell.

Designing the network detector and evaluating the global performance probabilities is a complicated task requiring high computational costs that grow as $N^{2^{b}-1}$, where N is the number of sensors and b is the number of bits per local detector. This renders their direct evaluation infeasible, except when the number of sensors N or the number of bits b per sensor is small. The literature usually avoids the direct computation of the performance probabilities by evaluating their asymptotic exponential decay rate, e.g., given by the Chernoff and Kullback-Leibler (KL) distances. These are in certain cases simple to compute, but, we emphasize, such measures estimate the asymptotic exponential decay rate of the performance probabilities, not the probabilities themselves. Chernoff and KL distances do not help with evaluating the receiver operating characteristics (ROC), or designing the fusion rule, say under the Neyman-Pearson criterion, since both require the actual detection and false alarm probabilities and not their decay rates. In addition, asymptotic measures are derived under limiting conditions, and thus, one has to make sure that these conditions are satisfied before adopting such measures in practical scenarios. To evaluate the detection performance probabilities, some authors use the normal approximation. The normal approximation can handle many practical problems, but fails often to provide acceptable accuracy, especially when the points to be approximated are in the tail regions and far from the mean of the decision variable. Simulations show that the normal approximation performs better with smaller networks but its accuracy deteriorates rapidly as the network size increases.

We have developed a different approach that enables the analysis and design of networks of arbitrary size (small or large) by considering a large deviation theory based approximation to the error probabilities that is both simple to compute and accurate. We adopt the saddlepoint approximation, which has been used in many applications such as optical detection, bootstrapping, and queuing analysis. It could also be related to the method of stationary phase, which is used widely in Physics. Although based on asymptotic expansions, the saddlepoint approximation is highly accurate even for networks with a few number of sensors. In addition, remarkably, the computational complexity of the saddlepoint approximation is independent of the number of sensors. We provide numerical comparisons to illustrate the advantage of the saddlepoint approximation over other approximation methods under different conditions. We show that the saddlepoint formulas are an accurate approximation in practical scenarios involving identical or non-identical observations, identical or non-identical local detectors, and reliable or unreliable communication links between the sensors and the fusion center.

With the saddlepoint approximation to design the Neyman-Pearson and the Bayes' detectors for a parallel architecture where the local sensors make a decision based on their measurements, quantize this local decision, and transmit it through a rate constrained channel to a fusion center. The network detector is composed of the local detetectors and the fusion rule at the fusion center. We demonstrated the probability of false alarm, the probability of detection, and the average probability of error.

Network Tradeoffs

We used the saddlepoint approximation to study tradeoffs among network parameters: number of sensors N, signal-to-noise ratio (SNR), and number of bits per local decision, subject to maximum rate constraint, i.e., subject to Nb = constant. Our results quantify for the same error performance what is the excess SNR needed when only N/2 sensors are used, each sensor quantizing their local decision with 2b bits, versus when N sensors are used with b bits per local decision. The results on the saddlepoint approximation, its use in designing the Neyman-Pearson and Bayes' detectors, computing the error detection performance, and studying network parameter tradeoffs are detailed in references [1] though [9].

Network Topology Design

The problem of network topology design is the following. Let N local decision makers in a sensor network communicate with their neighbors to reach a decision consensus. Communication is local, among neighboring sensors only, through noiseless or noisy links. We show that the topology of the network has a major impact on the convergence of distributed inference algorithms, namely, that these algorithms converge much faster for certain connectivity patterns than for others, thus requiring much less intersensor communication and power expenditure. We studied the design of the network topology that optimizes the rate of convergence of the iterative decision consensus algorithm. We reformulate the topology design problem as a spectral graph design problem, namely, maximizing the eigenratio of two eigenvalues of the graph Laplacian L, a matrix that is naturally associated with the interconnectivity pattern of the network. This reformulation avoids costly Monte Carlo simulations and leads to the class of non-bipartite Ramanujan graphs for which we find a lower bound on the eigenratio parameter. For Ramanujan topologies and noiseless links, the local probability of error converges much faster to the overall global probability of error than for structured graphs, random graphs, or graphs exhibiting small-world characteristics. With noisy links, we determine the optimal number of iterations before calling a decision. Finally, we introduce a new class of random graphs that are easy to construct, can be designed with arbitrary number of sensors, and whose spectral and convergence properties make them practically equivalent to Ramanujan topologies.

The literature on topology design for distributed detection is scarce. Usually, the underlying communication graph is specified ab initio as a structured graph, e.g., parallel networks where sensors communicate with a fusion center, e.g.,Tenney and Sandell, 1981, Tsitsiklis, 1988, Tsitsiklis, 1993, Willett, 2000, or serial networks where communication proceeds sequentially from a sensor to the next; for these and other similar architectures, see Varshney, 1996, Blum, 1997, Chamberland, 2003. These networks may not be practical; e.g., a parallel network depends on the integrity of the fusion center.

We published preliminary results on topology design for distributed inference problems in [2], [3]. We restricted the class of topologies to structured graphs, random graphs obtained with the Erdos-Renyi construction, and random constructions that exhibit small-world characteristics. We considered tradeoffs among these networks, their number of links M, and the number of bits b quantizing the state of the network at each sensor, under a global rate constraint, i.e., Mb=K, K fixed. We adopted as criterion the convergence of the average probability of error Pe, which required extensive simulation studies to find the desired network topology.

Our recent work, [11], [12], designs good topologies for sensor networks, in particular, with respect to the rate of convergence of iterative consensus and distributed detection algorithms. We consider the two cases of noiseless and noisy network links. We assume that the total number M of communication links between sensors is fixed and that the graph weights are uniform across all network links. The optimal topology maximizes the convergence rate of the consensus algorithm, i.e., minimizes the number of iterations needed for the average probability of error of the local detector at each sensor to be within a small espilon of the minimum probability of error (given by a centralized fusion center architecture.) Our work shows that, for both the iterative average-consensus and the distributed detection problems, the topology design problem is equivalent to the problem of maximizing with respect to the network topology a certain graph spectral parameter. This parameter is the ratio of the algebraic connectivity of the graph over the largest eigenvalue of the graph Laplacian L. The algebraic connectivity of a graph, terminology introduced by Fiedler, 1973, is the second smallest eigenvalue of its discrete Laplacian. With this reinterpretation, we showed that the class of Ramanujan graphs essentially provides the optimal network topologies, exhibiting remarkable convergence properties, orders of magnitude faster than other structured or random small-world like networks. When the links are noisy, our analysis determines what is the optimal number of iterations to declare a decision. Finally, we presented a new class of random regular graphs whose performance is very close to the performance of Ramanujan graphs. These graphs can be designed with arbitrary number of nodes, overcoming the limitation that the available constructions of Ramanujan graphs are restricted to networks whose number of sensors are limited to a sparse subset of the integers. References [11] and [12] summarize and detial this work.

Number of Peer Reviewed Papers: 1
(a) Papers published in peer-reviewed journals:

[1] Saeed Aldosari and José M. F. Moura, "Detection in Sensor Networks: The Saddlepoint Approximation," IEEE Transactions on Signal Processing, accepted for publication on February 2006, to be published in vol. 54 (12), December 2006.

Number of Non Peer Reviewed Papers: 1
(b) Papers published in non-peer-reviewed journals or in conference proceedings: 6

[2] Saeed Aldosari and José M. F. Moura, "Topology of Sensor Networks in Distributed Detection," ICASSP'06, IEEE International Conference on Signal Processing, Toulouse, France, May 14-21, 2006, invited paper in Special Session on Sensor Networks.

[3] Saeed Aldosari and José M. F. Moura, "Distributed Detection in Sensor Networks: Connectivity Graph and Small World Networks," The 39th Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, October 30 – November 2 , 2005.

[4] Saeed Aldosari and José M. F. Moura, "Saddle Point Approximation for Sensor Network Optimization,"ICASSP'05, IEEE International Conference on Signal Processing, Philadelphia, PA, March 18-23, 2005.

[5] Saeed Aldosari and José M. F. Moura, "Detection in Decentralized Sensor Networks," ICASSP'04, IEEE International Conference on Signal Processing, Montreal, Québec, Canada, May 17-21, 2004.

[6] Elijah Liu and José M. F. Moura "Fusion in Sensor Networks: Convergence Study," ICASSP'04, IEEE International Conference on Signal Processing, Montreal, Québec, Canada, May 17-21, 2004, Special Session on Sensor Networks.

[7] Saeed Aldosari and José M. F. Moura, "Fusion in Sensor Networks with Communication Constraints," IPSN'04 Information Processing in Sensor Networks, Berkeley California, April 2004.

Number of Papers not Published: 2
(c) Papers presented at meetings, but not published in conference proceedings (N/A for none)
[8] Saeed Aldosari and José M. F. Moura, "Fusion in Sensor Networks," Frontiers in Optics, Optical Society of America 88th Annual Meeting, Rochester, NY, October 10-14, 2004. Invited paper.

[9] José M. F. Moura, "Sensor Networks: Challenges and Applications," Next Wave Digital Home/Community Products, Services, and Opportunities Symposium, Keynote speaker, Institute for Information Industry, Taipei, Taiwan.

Number of Manuscripts: 1
(d) Manuscripts submitted, but not published (N/A for none)

[10] Soummya Kar, Saeed Aldosari, and José M. F. Moura, "Topology for Distributed Inference on Graphs," submitted for Journal publication, June 2006, 30 pages.

[11] Soummya Kar and José M. F. Moura, "Topology for Global Average Consensus," submitted for Conference publication, June 2006, 30 pages.

Number of Books: 0
(d) Books (N/A for none)

Honors and Awards
• Elected AAAS Fellow
• Member, NSF Committee of Visitors (COV), Computing and Communication Foundations Division, Directorate for Computer and Information Science and Engineering, June 15-16, 2006.
• President Elect of IEEE Signal Processing Society for period 2006-2007 to succeed as President for period of 2008-2009.
• Invited Speaker, University of Massachusetts, Amherst, MA, Mar 3, 2006.
• Invited Speaker, IBM T. J. Watson Research Center, Hawthorne, NY, February 23, 2006.
• Invited Speaker and Panel Member, Robust Signal Processing and Stochastic Eigen-Analysis Workshop (SEA05), Hosted by Department of Mathematics and Center for Ocean Engineering, MIT, October 14-15, 2005.
• Invited Speaker, 2nd IEEE/CreateNet Workshop on BroadBand Advanced Sensor Networks (BaseNetS 2005), Radisson Hotel, Boston, MA, October 3, 2005.
• Member of External Advisory Board, Network of Excellence on the Application and Communication Aspects of Wireless Sensor Networking (CRUISE), European Consortium of Universities, National Labs, and Industrial Research Labs on Sensor Networks, since September 2005–present.
• Member of Panel on Wireless Sensor Networks –From Sensor Networks to Smart Dust, at the 16TH IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications, Berlin, Germany, September 12-14, 2005.
• Invited Speaker, “Banff International Research Station Multimedia and Mathematics Workshop,” Banff, Alberta, Canada, July 24-27, 2005.
• NSF Science Research Centers Panel Review Member, review Center for Embedded Network Sensing, UCLA, June 15-17, 2005.
• Invited speaker, “ARO/AMRDEC Workshop on Information Theoretic Image Processing,” ARO/AMRDEC Workshop, Redstone Arsenal, Huntsville, AL, June 14-15, 2005.
• Invited speaker, “Sensor Networks: Detection and Estimation under Constraints,” SENSIP Workshop, Tempe, Arizona, April 28-29, 2005.
• Steering committee member, ACM/IEEE International Symposium in Information Processing in Sensor Networks, 2005-.
• Keynote speaker, “Sensor Networks: Challenges and Applications,” Next Wave Digital Home, Community Products, Services, and Opportunities Symposium, Institute for Information Industry, Taipei, Taiwan, November 2004.
• Invited talk Frontiers in Optics FiO'04, October 2004.
• Member of Panel on Sensor Networks - Interacting with the Real World, at the 15TH IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications, Barcelona, Spain, September 2004.
• Distinguished Lecturer IEEE Sensor and Multichannel Array Processing (SAM’04), July 2004.
• Plenary Speaker IEEE 5th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC’04), July 2004.
• Invited speaker, IBM T. J. Watson Research Laboratory, Hawthorne, NY, March 2004.
• Member of founding Editorial Board, ACM Journal on Sensors Networks, January 2004.
• Book Series Editor, Lectures in Signal Processing, Morgan & Claypool Publisher (January 2004–)
• Guest co-Editor, IEEE Signal Processing Magazine Special Issue on Iterative, Soft Signal Processing for Communications, January 2004.

- Invited Speaker, Statistical and Applied Mathematical Sciences Institute, SAMSI Sensors Network Workshop, Research Triangle Park, NC, October 2003
- Invited Speaker, IBM T. J. Watson Research Lab, Yorktown Heights, NY, December 2002.
- Science Foundation Ireland, Baseline Assessment Public Research System in Ireland, Information and Communications Technologies (June 2002)
- Member, Editorial Board, IEEE Signal Processing Magazine (2003–).
- Chair, IEEE Technical Activities Board (TAB) Transactions Committee (joining all 70+ IEEE Transactions and Journals) (2002-2003).

Scientific personnel showing any advanced degrees earned by them while employed on the project

PhD Graduate Students:
Saeed Aldosari, PhD awarded, December 2005.
Haotian Zhang, PhD awarded, December 2005.
David Sepiashvili, PhD May 2006.
Usman Khan (entered the PhD program on September 2005)
Soummya Khar (entered the PhD program on September 2005)

MSc Graduate Students:
Neeti Gore, MSc awarded, September 2005.
Elijah Liu, MSc awarded, December 2004.
Nehemiah Liu, MSc awarded, December 2004.

Other graduate students (graduate research project):
Malolan Santhanakrishnan
Priyanka Luhadia

Under Graduate Students:
Lionel Coulot, junior

Faculty Supported:
José M. F. Moura, Rohit Negi, Markus Pueschel
Names of Other Research Staff Supported:
Number of Patents Disclosed: None
Number of Patents Awarded: None
List of patent titles awarded:
Technology Transfer (any specific interactions or developments which would constitute technology transfer of the research results). We have maintained contacts with Northrup-Grumman, Raytheon, and Lockeed-Martin, with visits to their facilities to discuss sensing and sensor network research. We gave three invited talks at IBM T. J. Watson Research in NY to present our sensor network research results.

REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause) (See Instructions on back)

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PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THE ABOVE ORGANIZATION. RETURN COMPLETED FORM TO THE CONTRACTING OFFICER.

1.a. NAME OF CONTRACTOR/SUBCONTRACTOR	c. CONTRACT NUMBER	2.a. NAME OF GOVERNMENT PRIME CONTRACTOR	c. CONTRACT NUMBER	3. TYPE OF REPORT *(X one)*
Carnegie Mellon University	DAAD190210180	US Army Research Office	DAAD190210180	a. INTERIM ☐ / b. FINAL ✗

b. ADDRESS *(Include ZIP Code)*	d. AWARD DATE *(YYYYMMDD)*	b. ADDRESS *(Include ZIP Code)*	d. AWARD DATE *(YYYYMMDD)*	4. REPORTING PERIOD *(YYYYMMDD)*
5000 Forbes Avenue Pittsburgh PA 15213-3890	20020601	POBox 12211 Research Triangle Park, NC 27709-2211	2002 06 01	a. FROM 20020601 b. TO 20061130

SECTION I - SUBJECT INVENTIONS

5. "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR/SUBCONTRACTOR *(If "None," so state)*

NAME(S) OF INVENTOR(S) *(Last, First, Middle Initial)* a.	TITLE OF INVENTION(S) b.	DISCLOSURE NUMBER, PATENT APPLICATION SERIAL NUMBER OR PATENT NUMBER c.	ELECTION TO FILE PATENT APPLICATIONS *(X)* d. (1) UNITED STATES (a) YES	(1) UNITED STATES (b) NO	(2) FOREIGN (a) YES	(2) FOREIGN (b) NO	CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER *(X)* e. (a) YES	e. (b) NO
NONE		NONE						

f. EMPLOYER OF INVENTOR(S) NOT EMPLOYED BY CONTRACTOR/SUBCONTRACTOR

(1)	(2)
(a) NAME OF INVENTOR *(Last, First, Middle Initial)*	(a) NAME OF INVENTOR *(Last, First, Middle Initial)*
(b) NAME OF EMPLOYER	(b) NAME OF EMPLOYER
(c) ADDRESS OF EMPLOYER *(Include ZIP Code)*	(c) ADDRESS OF EMPLOYER *(Include ZIP Code)*

g. ELECTED FOREIGN COUNTRIES IN WHICH A PATENT APPLICATION WILL BE FILED

(1) TITLE OF INVENTION	(2) FOREIGN COUNTRIES OF PATENT APPLICATION
NONE	

SECTION II - SUBCONTRACTS *(Containing a "Patent Rights" clause)*

6. SUBCONTRACTS AWARDED BY CONTRACTOR/SUBCONTRACTOR *(If "None," so state)*

NAME OF SUBCONTRACTOR(S) a.	ADDRESS *(Include ZIP Code)* b.	SUBCONTRACT NUMBER(S) c.	FAR "PATENT RIGHTS" d. (1) CLAUSE NUMBER	d. (2) DATE *(YYYYMM)*	DESCRIPTION OF WORK TO BE PERFORMED UNDER SUBCONTRACT(S) e.	SUBCONTRACT DATES *(YYYYMMDD)* f. (1) AWARD	f. (2) ESTIMATED COMPLETION
NONE							

SECTION III - CERTIFICATION

7. CERTIFICATION OF REPORT BY CONTRACTOR/SUBCONTRACTOR *(Not required if: (X as appropriate))* ☐ SMALL BUSINESS or ✗ NONPROFIT ORGANIZATION

I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all "Subject Inventions" have been reported.

a. NAME OF AUTHORIZED CONTRACTOR/SUBCONTRACTOR OFFICIAL *(Last, First, Middle Initial)*	b. TITLE	c. SIGNATURE	d. DATE SIGNED
MOURA, Jose M. F.	Professor	José Manuel Fonseca de Moura	June 12/ 2006

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DD FORM 882 INSTRUCTIONS

GENERAL

This form is for use in submitting INTERIM and FINAL invention reports to the Contracting Officer and for use in reporting the award of subcontracts containing a "Patent Rights" clause. If the form does not afford sufficient space, multiple forms may be used or plain sheets of paper with proper identification of information by item number may be attached.

An INTERIM report is due at least every 12 months from the date of contract award and shall include (a) a listing of "Subject Inventions" during the reporting period, (b) a certification of compliance with required invention identification and disclosure procedures together with a certification of reporting of all "Subject Inventions," and (c) any required information not previously reported on subcontracts containing a "Patent Rights" clause.

A FINAL report is due within 6 months if contractor is a small business firm or domestic nonprofit organization and within 3 months for all others after completion of the contract work and shall include (a) a listing of all "Subject Inventions" required by the contract to be reported, and (b) any required information not previously reported on subcontracts awarded during the course of or under the contract and containing a "Patent Rights" clause.

While the form may be used for simultaneously reporting inventions and subcontracts, it may also be used for reporting, promptly after award, subcontracts containing a "Patent Rights" clause.

Dates shall be entered where indicated in certain items on this form and shall be entered in six or eight digit numbers in the order of year and month (YYYYMM) or year, month and day (YYYYMMDD). Example: April 1999 should be entered as 199904 and April 15, 1999 should be entered as 19990415.

1.a. Self-explanatory.

1.b. Self-explanatory.

1.c. If "same" as Item 2.c., so state.

1.d. Self-explanatory.

2.a. If "same" as Item 1.a., so state.

2.b. Self-explanatory.

2.c. Procurement Instrument Identification (PII) number of contract (DFARS 204.7003).

2.d. through 5.e. Self-explanatory.

5.f. The name and address of the employer of each inventor not employed by the contractor or subcontractor is needed because the Government's rights in a reported invention may not be determined solely by the terms of the "Patent Rights" clause in the contract.

Example 1: If an invention is made by a Government employee assigned to work with a contractor, the Government rights in such an invention will be determined under Executive Order 10096.

Example 2: If an invention is made under a contract by joint inventors and one of the inventors is a Government employee, the Government's rights in such an inventor's interest in the invention will also be determined under Executive Order 10096, except where the contractor is a small business or nonprofit organization, in which case the provisions of 35 U.S.C. 202(e) will apply.

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5.g.(2) Self-explanatory with the exception that the contractor or subcontractor shall indicate, if known at the time of this report, whether applications will be filed under either the Patent Cooperation Treaty (PCT) or the European Patent Convention (EPC). If such is known, the letters PCT or EPC shall be entered after each listed country.

6.a. Self-explanatory.

6.b. Self-explanatory.

6.c. Self-explanatory.

6.d. Patent Rights Clauses are located in FAR 52.227.

6.e. Self-explanatory.

6.f. Self-explanatory.

7. Certification not required by small business firms and domestic nonprofit organizations.

7.a. through 7.d. Self-explanatory.