

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188		
<p>The 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. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>					
1. REPORT DATE (DD-MM-YYYY) 15-08-2014		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) 15-Jun-2007 - 19-May-2014	
4. TITLE AND SUBTITLE Engineering of Sensor Network Structure for Dependable Fusion			5a. CONTRACT NUMBER W911NF-07-1-0376		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER 611103		
			5d. PROJECT NUMBER		
6. AUTHORS Shashi Phoha			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES Pennsylvania State University 110 Technology Center University Park, PA 16802 -7000			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSOR/MONITOR'S ACRONYM(S) ARO		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) 52539-CS-MUR.156		
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. 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.					
14. ABSTRACT The primary objective of this MURI research is to develop the theory and operation of heterogeneous sensor networks that can provide a desired quality of sensor fusion for creating actionable situation awareness. This goal is being achieved by developing (i) Mathematically rigorous and novel language theoretic sensor data representation and multi-level heterogeneous sensor fusion techniques that require substantially less sensing and communication resources as compared to conventional techniques, and (ii) Fusion-driven dynamic control and adaptation of heterogeneous sensor networks.					
15. SUBJECT TERMS Decision support systems, Dynamic data driven application systems (DDDAS), DFIG data fusion, Progressive unmanned sensing, Heterogeneous sensor networks, Contextual decision making					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU	UU		Shashi Phoha
					19b. TELEPHONE NUMBER 814-863-8005

Report Title

Final Report

ABSTRACT

The primary objective of this MURI research is to develop the theory and operation of heterogeneous sensor networks that can provide a desired quality of sensor fusion for creating actionable situation awareness. This goal is being achieved by developing (i) Mathematically rigorous and novel language theoretic sensor data representation and multi-level heterogeneous sensor fusion techniques that require substantially less sensing and communication resources as compared to conventional techniques, and (ii) Fusion-driven dynamic control and adaptation of heterogeneous sensor networks.

Individual sensors have limited computing, energy and communication resources, whereas the information processing required to extract actionable situation awareness from a network of such sensors is highly complex. These conflicts led us to design a novel sensor architecture that partitioned the overall design into two separate but interacting design spaces, (1) Information Space (IS): deals with all the information processing tasks, e.g., sensor data coding, compression and fusion, and (2) Network Design Space (NS): deals with all the sensor networking, communication and network control & adaptation tasks.

In addition to the theoretical research, our research also involves experimental validation of the individual theoretical research problems as well as integrated research. For this purpose, we have created a sensor network test bed consisting of a sensor network simulator integrated with real sensor nodes and real sensor networks. This test bed has been successfully used to test the Heterogeneous Dynamic Space Time Clustering (HDSTC) for target tracking. The HDSTC also integrates research ideas from all the MURI team members.

Major innovations of this year, outlined in following sections of this report, have been: (i) contextual semantic reasoning, learning and adaptation, making use of influence diagrams and dynamic decision networks; (ii) exploitation of cross-modal sensor dependencies; (iii) semantic fusion for upper layer control; and (iv) complete coverage of search area for a single robot.

The results of this research have led to formal techniques for multi-level fusion of heterogeneous sensor data and have furthered efforts to design engineered sensor networks whose structure is simultaneously adaptive, near optimal and resilient to events caused by either the sensed environment or the inherent network behaviors. The outcomes of this research when incorporated into real DoD sensor systems will lead to systems capable of robust context-adaptive and dependable surveillance with minimal human dependence.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

<u>Received</u>	<u>Paper</u>
05/19/2014 54.00	Xin Jin, Asok Ray. Navigation of autonomous vehicles for oil spill cleaning in dynamic and uncertain environments, International Journal of Control, (04 2014): 787. doi: 10.1080/00207179.2013.858829
05/19/2014 52.00	Siddharth Sonti, Eric Keller, Joseph Horn, Asok Ray. Stability Monitoring of Rotorcraft Systems: A Dynamic Data-Driven Approach, Journal of Dynamic Systems, Measurement, and Control, (01 2014): 0. doi: 10.1115/1.4025988
05/19/2014 55.00	Kushal Mukherjee, Asok Ray. State splitting and merging in probabilistic finite state automata for signal representation and analysis, Signal Processing, (11 2014): 105. doi: 10.1016/j.sigpro.2014.03.045
05/20/2013 25.00	Yicheng Wen, Doina Bein, Shashi Phoha. Dynamic clustering of multi-modal sensor networks in urban scenarios, Information Fusion, (10 2012): 0. doi: 10.1016/j.inffus.2012.09.003
07/03/2013 26.00	Pankaj K. Agarwal, Lars Arge, Peyman Afshani, Kasper Green Larsen, Jeff M. Phillips. (Approximate) Uncertain Skylines, Theory of Computing Systems, (02 2012): 0. doi: 10.1007/s00224-012-9382-7
07/03/2013 45.00	Roger Brockett. Synchronization without periodicity, Mathematical Systems Theory, (01 2013): 65. doi:
07/03/2013 43.00	Albert Yu, Pankaj K. Agarwal, Jun Yang. Subscriber Assignment for Wide-Area Content-Based Publish/Subscribe, IEEE Transactions on Knowledge and Data Engineering, (10 2012): 0. doi: 10.1109/TKDE.2012.65
07/03/2013 36.00	Srikanth Hariharan, Zizhan Zheng, Ness B. Shroff. Maximizing Information in Unreliable Sensor Networks Under Deadline and Energy Constraints, IEEE Transactions on Automatic Control, (06 2013): 1416. doi: 10.1109/TAC.2013.2244311
07/03/2013 35.00	Srikanth Hariharan, Ness B. Shroff. On Sample-Path Optimal Dynamic Scheduling for Sum-Queue Minimization in Forests, IEEE/ACM Transactions on Networking, (02 2013): 0. doi: 10.1109/TNET.2013.2245339
07/03/2013 34.00	Changhee Joo, Ness B. Shroff. On the Delay Performance of In-Network Aggregation in Lossy Wireless Sensor Networks, IEEE/ACM Transactions on Networking, (04 2013): 0. doi: 10.1109/TNET.2013.2256795
07/03/2013 33.00	Soumik Sarkar, Kushal Mukherjee, Asok Ray. Distributed decision propagation in mobile-agent proximity networks, International Journal of Control, (06 2013): 0. doi: 10.1080/00207179.2013.782511
07/03/2013 32.00	Yicheng Wen, Asok Ray, Shashi Phoha. Hilbert space formulation of symbolic systems for signal representation and analysis, Signal Processing, (09 2013): 0. doi: 10.1016/j.sigpro.2013.02.002
07/03/2013 31.00	Soumalya Sarkar, Kushal Mukherjee, Soumik Sarkar, Asok Ray. Symbolic Dynamic Analysis of Transient Time Series for Fault Detection in Gas Turbine Engines, Journal of Dynamic Systems, Measurement, and Control, (01 2013): 0. doi: 10.1115/1.4007699

- 07/03/2013 30.00 Devesh K. Jha, Asok Ray, Kushal Mukherjee, Subhadeep Chakraborty. Classification of Two-Phase Flow Patterns by Ultrasonic Sensing, *Journal of Dynamic Systems Measurement and Control*, (11 2012): 0. doi: 10.1115/1.4007555
- 07/03/2013 29.00 Soumik Sarkar, Soumalya Sarkar, Kushal Mukherjee, Asok Ray, Abhishek Srivastav. Multi-sensor information fusion for fault detection in aircraft gas turbine engines, *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, (12 2012): 0. doi: 10.1177/0954410012468391
- 08/09/2012 20.00 Shashi Phoha, Goutham Mallapragada, Yicheng Wen, Doina Bein, Asok Ray. DESIGNING A FUSION-DRIVEN SENSOR NETWORK TO SELECTIVELY TRACK MOBILE TARGETS ^L, *Parallel Processing Letters*, (03 2012): 0. doi:
- 08/09/2012 21.00 Subhadeep Chakraborty, Soumik Sarkar, Asok Ray. Symbolic Identification for Fault Detection in Aircraft Gas Turbine Engines, *Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, (04 2012): 422. doi:
- 08/10/2011 22.00 S. Sankararaman, A. Efrat, S. Ramasubramanian, P. K. Agarwal. On Channel-Discontinuity-Constraint Routing in Wireless Networks, *Ad-Hoc Networks*, 2011, (04 2011): 1. doi:
- 08/10/2011 21.00 Pankaj K. Agarwal, Siu-Wing Cheng, Yufei Tao, Ke Yi,, . Range Searching on Uncertain Data, *ACM Transactions on Algorithms*, (12 2011): 1. doi:
- 08/10/2011 23.00 Pankaj K. Agarwal , Esther Ezra , Micha Sharir. Near-Linear Approximation Algorithms for Geometric Hitting Sets, *Algorithmica*, (05 2011): 1. doi:
- 08/10/2011 1.00 Joohwan Kim, Xiaojun Lin, Ness B. Shroff. Optimal Anycast Technique for Delay-Sensitive Energy-Constrained Asynchronous Sensor Networks, *IEEE/ACM Transactions on Networking*, (04 2011): 484. doi: 10.1109/TNET.2010.2072515
- 08/10/2011 2.00 Yan Wu, Zhoujia Mao, Sonia Fahmy, Ness B. Shroff. Constructing Maximum-Lifetime Data-Gathering Forests in Sensor Networks, *IEEE/ACM Transactions on Networking*, (10 2010): 1571. doi: 10.1109/TNET.2010.2045896
- 08/10/2011 4.00 Aparna Subbu, Abhishek Srivastav, Asok Ray, Eric Keller. Symbolic Dynamic Filtering for Image Analysis: Theory and Experimental Validation, *Signal, Image and Video Processing*, (6 2009): 319. doi: 10.1007/s11760-009-0122-7
- 08/10/2011 7.00 Doina Bein, Yicheng Wen, Shashi Phoha, Bharat B. Madan, Asok Ray. Distributed Network Control for Mobile Multi-Modal Wireless Sensor Networks, *Journal of Parallel and Distributed Computing*, (03 2011): 460. doi: 10.1016/j.jpdc.2010.08.016
- 08/10/2011 5.00 Yicheng Wen, Asok Ray. A Stopping Rule for Symbolic Dynamic Filtering, *Applied Mathematics Letters*, (09 2010): 1125. doi: 10.1016/j.aml.2010.04.048
- 08/10/2011 6.00 Kushal Mukherjee, Asok Ray, Thomas Wettergren, Shalabh Gupta, Shashi Phoha. Real-time Adaptation of Decision Thresholds in Sensor Networks for Detection of Moving Targets, *Automatica*, (01 2011): 185. doi: 10.1016/j.automatica.2010.10.031
- 08/10/2011 8.00 Kushal Mukherjee, Shalabh Gupta, Asok Ray, Shashi Phoha. Symbolic Analysis of Sonar Data for Underwater Target Detection, *IEEE Journal of Oceanic Engineering*, (04 2011): 219. doi: 10.1109/JOE.2011.2122590
- 08/10/2011 9.00 Kushal Mukherjee, Shalabh Gupta, Asok Ray, Thomas A. Wettergren. Statistical-Mechanics-Inspired Optimization of Sensor Field Configuration for Detection of Mobile Targets, *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, (06 2011): 783. doi: 10.1109/TSMCB.2010.2092763

- 08/10/2011 10.00 Xin Jin, Shalabh Gupta, Kushal Mukherjee, Asok Ray. Wavelet-based Feature Extraction Using Probabilistic Finite State Automata for Pattern Classification., Pattern Recognition, (07 2011): 1343. doi: 10.1016/j.patcog.2010.12.003
- 08/10/2011 11.00 Soumik Sarkar, Xin Jin, Asok Ray. Data-driven Fault Detection in Aircraft Engines with Noisy Sensor Measurements, Journal of Engineering for Gas Turbines and Power, (08 2011): 1. doi: 10.1115/1.4002877
- 08/10/2011 12.00 Yicheng Wen, Asok Ray, Qiang Du. A Variance-Estimation-Based Stopping Rule for Symbolic Dynamic Filtering, Signal, Image and Video Processing, (2 2011): 1. doi: 10.1007/s11760-011-0215-y
- 08/10/2011 25.00 Subhadeep Chakraborty, Soumik Sarkar, Asok Ray. Symbolic Identification for Fault Detection in Aircraft Gas Turbine Engines, Proceedings of the I Mech E Part G: Journal of Aerospace Engineering, (12 2011): 1. doi:
- 08/10/2011 55.00 Srikanth Hariharan, Ness B. Shroff. Maximizing Aggregated Information in Sensor Networks under Deadline Constraints, IEEE Transactions on Automatic Control special issue on Wireless Sensor and Actuator Networks, (01 2011): 1. doi:
- 08/10/2011 56.00 Eric Keller, Dmitry Gorodetsky , Shashi Phoha. Semantic Feature Extraction and Classification in a Distributed Sensor Network, Journal of Intelligence Community Research and Development, (10 2010): 1. doi:
- 08/10/2011 68.00 Pankaj K. Agarwal , Lars Arge, Haim Kaplan, Eyal Molad, Robert E. Tarjan, Ke Yi. An Optimal Dynamic Data Structure for Stabbing-Semigroup Queries, SIAM Journal on Computing, (12 2011): 1. doi:
- 08/10/2011 69.00 Abdeq M. Abdi, Mendel Schmiedekamp, Shashi Phoha. Probabilistic Color Matching and Tracking of Human Subjects, Applied Optics Journal, vol. 49, no. 26, pp. 4926-4935, September 2010., (09 2010): 4926. doi:
- 08/13/2012 22.00 Srikanth Hariharan, Ness B. Shroff. Maximizing Aggregated Information in Sensor Networks Under Deadline Constraints, IEEE Transactions on Automatic Control, (10 2011): 2369. doi:
- 08/15/2011 83.00 Shashi Phoha, Goutham Mallapragada, Yicheng Wen, Doina Bein, Asok Ray. Designing a Fusion-Driven Sensor Network to Selectively Track Mobile Targets, Parallel Processing Letters, (07 2011): 1. doi:
- 08/24/2012 24.00 Yicheng Wen, Kushal Mukherjee, Asok Ray. Adaptive pattern classification for symbolic dynamic systems, Signal Processing, (08 2012): 0. doi: 10.1016/j.sigpro.2012.08.002

TOTAL: 39

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

<u>Received</u>	<u>Paper</u>
07/03/2013 46.00	Pankaj K. Agarwal, Siu-Wing Cheng, Ke Yi. Range Searching on Uncertain Data, ACM Transactions on Algorithms, (08 2012): 0. doi:
TOTAL:	1

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>	<u>Paper</u>
07/29/2011 60.00	Pankaj K. Agarwal, Graham Cormode , Zengfeng Huang, Jeff M. Phillips, Zheiwei Wei, Ke Yi. Mergeable Summaries, Third Workshop on Massive Data Algorithmics (MASSIVE), 2011. , . : ,
TOTAL:	1

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>	<u>Paper</u>
05/19/2014 53.00	Pankaj K. Agarwal, Swaminathan Sankararaman, Thomas Mølhave, Jiangwei Pan, Arnold P. Boedihardjo. Model-driven matching and segmentation of trajectories, the 21st ACM SIGSPATIAL International Conference. 05-NOV-13, Orlando, Florida. : ,
07/03/2013 28.00	Pankaj K. Agarwal, Jiri Matouek, Micha Sharir. On Range Searching with Semialgebraic Sets II, 2012 IEEE 53rd Annual Symposium on Foundations of Computer Science (FOCS). 20-OCT-12, New Brunswick, NJ, USA. : ,
07/03/2013 44.00	Roger Brockett. Nonholonomic regulators, 2012 IEEE 51st Annual Conference on Decision and Control (CDC). 10-DEC-12, Maui, HI, USA. : ,
07/03/2013 41.00	Siddharth Sonti, Nurali Virani , Devesh K. Jha , Kushal Mukherjee , Asok Ray. Language Measure-theoretic Path Planning in the Presence of Dynamic Obstacles, 2013 American Control Conference. 17-JUN-13, . : ,
07/03/2013 42.00	Pankaj K. Agarwal, Boris Aronov, Sariel Har-Peled, Jeff M. Phillips, Ke Yi, Wuzhou Zhang. Nearest neighbor searching under uncertainty II, 32nd symposium Principles of database systems (PODS '13). 22-JUN-13, New York, New York, USA. : ,
07/03/2013 40.00	Xin Jin, Asok Ray. Coverage Control of Autonomous Vehicles for Oil Spill Cleaning in Dynamic and Uncertain Environments, 2013 American Control Conference. 17-JUN-13, . : ,
07/03/2013 37.00	Shashi Phoha, Asok Ray. An Artificial Language for Data-driven Self-adaptation of Networked Robots in Dynamic Environments, The 8th International Conference on Computer Science & Education (ICCSE 2013). 28-APR-13, . : ,
07/03/2013 27.00	You Wu, Pankaj K. Agarwal, Chengkai Li, Jun Yang, Cong Yu. On "one of the few" objects, the 18th ACM SIGKDD international conference. 12-AUG-12, Beijing, China. : ,
07/23/2012 97.00	Zizhan Zheng, Ness B. Shroff. Maximizing a Submodular Utility for Deadline Constrained Data Collection in Sensor Networks, IEEE 10th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOPT'12). 16-MAY-12, . : ,
07/23/2012 99.00	Shengbo Chen, Prasun Sinha, Ness B. Shroff, Changhee Joo. A Simple Asymptotically Optimal Energy Allocation and Routing Scheme in Rechargeable Sensor Networks, IEEE INFOCOM'12. 27-MAR-12, . : ,
07/23/2012 96.00	Soheil Eshghi, Saswati Sarkar, Ness B. Shroff, Santosh S. Venkatesh, MHR. Khouzani. Optimal Energy-Aware Epidemic Routing in DTNs, ACM Mobihoc 2012. 13-JUN-12, . : ,
07/23/2012 95.00	Matthew Jones, Doina Bein, Bharat B. Madan, Shashi Phoha. Increasing the Network Capacity for Multi-modal Multi-hop WSNs through Unsupervised Data Rate Adjustment ₁ , Intelligent Distributed Computing V Proceedings of the 5th International Symposium on Intelligent Distributed Computing – IDC 2011. 06-OCT-11, . : ,

- 07/23/2012 98.00 Atilla Eryilmaz, Ness B. Shroff, Wenzhuo Ouyang. Low-complexity Optimal Scheduling over Correlated Fading Channels with ARQ Feedback, IEEE 10th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOPT'12). 17-MAY-12, . : ,
- 07/24/2012 01.00 Srikanth Hariharan, Ness B. Shroff. On sample-path optimal dynamic scheduling for sum-queue minimization in trees under the K-hop interference model, IEEE INFOCOM 2012 - IEEE Conference on Computer Communications. 25-MAR-12, Orlando, FL, USA. : ,
- 07/24/2012 06.00 Albert Yu, Pankaj K. Agarwal, Jun Yang. Processing a large number of continuous preference top-k Queries, SIGMOD '12 International Conference on Management of Data. 20-MAY-12, Scottsdale, Arizona, USA. : ,
- 07/24/2012 08.00 Behtash Babadi, Vahid Tarokh. Regularized recursive least squares for anomaly detection in sparse channel tracking applications, the 2011 ACM Symposium. 02-NOV-11, Miami, Florida. : ,
- 07/24/2012 07.00 Behtash Babadi, Vahid Tarokh. Vertical spectrum sharing via distributed asynchronous interference avoidance in cognitive radio networks, 2012 IEEE Consumer Communications and Networking Conference (CCNC). 14-JAN-12, Las Vegas, NV, USA. : ,
- 07/24/2012 02.00 Pankaj K. Agarwal, Graham Cormode, Zengfeng Huang, Jeff Phillips, Zhewei Wei, Ke Yi. Mergeable summaries, the 31st symposium. 21-MAY-12, Scottsdale, Arizona, USA. : ,
- 07/24/2012 03.00 Pankaj K. Agarwal, Alon Efrat, Swaminathan Sankararaman, Wuzhou Zhang. Nearest-neighbor searching under uncertainty, the 31st symposium. 21-MAY-12, Scottsdale, Arizona, USA. : ,
- 07/24/2012 04.00 Alex Beutel, Thomas Mølhave, Pankaj K. Agarwal, Arnold P. Boedihardjo, James A. Shine. TerraNNI: natural neighbor interpolation on a 3D grid using a GPU, the 19th ACM SIGSPATIAL International Conference. 01-NOV-11, Chicago, Illinois. : ,
- 07/26/2012 11.00 Yiqun Wu, Ness B. Shroff, Zhisheng Niu. Energy Minimization in Cooperative Relay Networks with Sleep Mode, IEEE 10th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOPT'12). 17-MAY-12, . : ,
- 07/26/2012 12.00 R. Sharathkumar, Pankaj K. Agarwal. A near-linear time ϵ -approximation algorithm for geometric bipartite matching, the 44th symposium on Theory of Computing (STOC '12). 19-MAY-12, New York, New York, USA. : ,
- 07/26/2012 13.00 Pankaj K. Agarwal, R. Sharathkumar. Algorithms for the transportation problem in geometric settings, Proceedings of the Twenty-Third Annual ACM-SIAM Symposium on Discrete Algorithms (SODA '12). 17-JAN-12, . : ,
- 07/28/2011 27.00 Pankaj Agarwal, Alon Efrat, Shashidhara Ganjugunte, David Hay, Swaminathan Sankararaman, Gil Zussman. Network Vulnerability to Single, Multiple, and Probabilistic Physical Attacks, Proceedings Military Communications Conference, 2010- MILCOM . 31-OCT-10, . : ,
- 07/28/2011 59.00 Matthew Jones, Doina Bein, Bharat B. Madan, Shashi Phoha. Increasing the Network Capacity for Multi-modal Multi-hop WSNs through Unsupervised Data Rate Adjustment, The 5th International Symposium on Intelligent Distributed Computing. . : ,
- 07/28/2011 58.00 Srikanth Hariharan, Ness B. Shroff. On Optimal Energy Efficient Convergecasting in Unreliable Sensor Networks with Applications to Target Tracking, ACM Mobihoc 2011. 19-MAY-11, . : ,

- 07/28/2011 51.00 Xin Jin, Shalab Gupta, Asok Ray , Thyagaraju Damarla. Multimodal Sensor Fusion for Personnel Detection Using Unattended Ground Sensors, Fusion 2011. 06-JUL-11, . . . ,
- 07/28/2011 46.00 Yicheng Wen, Asok Ray, Ishanu Chattopadhyay, Shashi Phoha. Modeling of Symbolic Systems: Part II - Hilbert Space Construction for Model Identification and Order Reduction, 2011 American Control Conference. 01-JUL-11, . . . ,
- 07/28/2011 45.00 Yicheng Wen, Asok Ray , Ishanu Chattopadhyay , Shashi Phoha. Vector Space Formulation of Probabilistic Finite State Automata, 2011 American Control Conference. 01-JUL-11, . . . ,
- 07/28/2011 43.00 Dheeraj Singh, Soumik Sarkar, Shalabh Gupta , Asok Ray. Optimal Partitioning of Ultrasonic Data for Fatigue Damage Detection, 2011 American Control Conference. 29-JUN-11, . . . ,
- 07/28/2011 19.00 Soumik Sarkar, Kushal Mukherjee, Abhishek Srivastav, Asok Ray. Distributed Decision Propagation in Mobile Agent Networks, 2010 49th IEEE Conference on Decision and Control (CDC). 15-DEC-10, Atlanta, GA, USA. : ,
- 07/28/2011 40.00 Xin Jin, Jacqueline M. Luff, Shalabh Gupta, Asok Ray. Autonomous Vehicle Navigation with Dynamic Application and Complete Coverage of Unknown Environments., 3rd Annual ASME Dynamic Systems and Control Conference. 15-SEP-10, . . . ,
- 07/28/2011 39.00 Soumik Sarkar, Kushal Mukherjee, Xin Jin, Asok Ray. Optimization of Time-Series Data Partitioning for Parameter Identification, 3rd Annual ASME Dynamic Systems and Control Conference. 13-SEP-10, . . . ,
- 07/28/2011 36.00 Betash Babadi, Vahid Tarokh. Vertical Spectrum Sharing via Distributed Asynchronous Interference Avoidance in Cognitive Radio Networks, 9th Annual IEEE Consumer Communications and Networking Conference (CCNC'11). 09-JAN-11, . . . ,
- 07/28/2011 35.00 Alan O'Connor. Measurement of a Jump-Markov Process: When is it too Costly?, 2011 IEEE Conference on Decision and Control . 12-DEC-11, . . . ,
- 07/28/2011 33.00 Srikanth Hariharan, Ness B. Shroff. On Optimal Dynamic Scheduling for Sum-Queue Minimization in Trees, IEEE 9th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOPT'11). 11-MAY-11, . . . ,
- 07/28/2011 30.00 Pankaj Agarwal, Alon Efrat, Chris Gniady, Joseph Mitchell, Valentin Polishchuk, Girishkumar Sabhnani. Distributed Localization and Clustering Using Data Correlation and the Occam's Razor Principle, The 7th IEEE International Conference on Distributed Computing in Sensor Systems (IEEE DCOSS '11). 27-MAY-11, . . . ,
- 07/28/2011 14.00 Pankaj K. Agarwal, Alon Efrat, Shashidhara Ganjugunte, David Hay, Swaminathan Sankararaman, Gil Zussman. The resilience of WDM networks to probabilistic geographical failures, IEEE INFOCOM 2011 - IEEE Conference on Computer Communications. 10-APR-11, Shanghai, China. : ,
- 07/28/2011 13.00 Alex Beutel, Thomas Mølhave, Pankaj K. Agarwal. Natural Neighbor Interpolation Based Grid DEM Construction using a GPU, the 18th SIGSPATIAL International Conference on Advances in Geographic Systems. 02-NOV-10, San Jose, California. : ,
- 07/28/2011 26.00 Pankaj Agarwal, Jeff Phillips, Hai Yu. Stability of eps-Kernels, Proceedings of the Eighteenth European Symposium on Algorithms, 2010. 07-AUG-10, . . . ,
- 08/04/2011 67.00 Alan C. O'Conner. Measurement of a Markov Jump Process by Hypothesis Tests, 9th IEEE International Conference on Control & Automation (ICCA'11) . 19-DEC-11, . . . ,

- 08/07/2012 15.00 Yicheng Wen, Kushal Mukherjee , Asok Ray. Adaptation in Symbolic Dynamic Systems for Pattern Classification, 2012 American Control Conference. 27-JUN-12, . . . ,
- 08/07/2012 19.00 Soumalya Sarkar , Kushal Mukherjee , Soumik Sarkar, Asok Ray. Symbolic Transient Time-series Analysis for Fault Detection in Aircraft Gas Turbine Engines, 2012 American Control Conference. 27-JUN-12, . . . ,
- 08/07/2012 18.00 Soumik Sarkar , Kushal Mukherjee , Asok Ray. Distributed Decision Propagation in Mobile Agent Networks, 2012 American Control Conference. 27-JUN-12, . . . ,
- 08/07/2012 17.00 Shalabh Gupta , Jacqueline M. Luff , Asok Ray, Xin Jin . Multi-Resolution Navigation of Mobile Robots with Complete Coverage of Unknown and Complex Environments, 2012 American Control Conference. 27-JUN-12, . . . ,
- 08/07/2012 16.00 Yicheng Wen, Soumalya Sarkar, Asok Ray, Xin Jin, Thyagaraju Damarla. A Unified Framework for Supervised Learning of Semantic Models₁, 2012 American Control Conference. 27-JUN-12, . . . ,
- 08/11/2011 29.00 Pankaj K. Agarwal, Thomas Mølhave, Hai Yu, James S. Clark. Exploiting Temporal Coherence in Forest Dynamics Simulation, Twenty-Seventh Annual Symposium on Computational Geometry, 2011. 13-MAY-11, . . . ,
- 08/11/2011 28.00 Pankaj K. Agarwal, Thomas Mølhave, Bardia Sadri. I/O-Efficient Contour Queries on Terrains, Proceedings of the Twenty-Second Annual ACM-SIAM Symposium on Discrete Algorithms, 2011. 23-JAN-11, . . . ,
- 08/11/2011 31.00 Srikanth Hariharan, Ness B. Shroff. Deadline Constrained Scheduling for Data Aggregation in Unreliable Sensor Networks, IEEE 9th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOPT'11). 09-MAY-11, . . . ,
- 08/11/2011 15.00 Srikanth Hariharan, Leonardo R. Bachega, Ness B. Shroff, Charles A. Bouman. Communication Efficient Signal Detection in Correlated Clutter for Wireless Sensor Networks, 2010 44th Asilomar Conference on Signals, Systems and Computers. 07-NOV-10, Pacific Grove, CA, USA. . . . ,
- 08/11/2011 17.00 Shengbo Chen, Prasun Sinha, Ness B. Shroff, Changhee Joo. Finite-Horizon Energy Allocation and Routing Scheme in Rechargeable Sensor Networks, IEEE INFOCOM 2011 - IEEE Conference on Computer Communications. 10-APR-11, Shanghai, China. : ,
- 08/11/2011 42.00 Soumik Sarkar, Dheeraj S. Singh, Abhishek Srivastav, Asok Ray. Semantic Sensor Fusion for Fault Diagnosis in Aircraft Gas Turbine Engines, 2011 American Control Conference. 29-JUN-10, . . . ,
- 08/11/2011 44.00 Abhishek Srivastav, Yicheng Wen, Evan Hendrick, Ishanu Chattopadhyay, Asok Ray, Shashi Phoha, . Information Fusion for Object & Situation Assessment in Sensor Networks, 2011 American Control Conference. 29-JUN-11, . . . ,
- 08/11/2011 47.00 Patrick Adenis, Kushal Mukherjee, Asok Ray. State Splitting and State Merging in Probabilistic Finite State Automata, 2011 American Control Conference. 01-JUL-11, . . . ,
- 08/11/2011 48.00 Xin Jin, Shalabh Gupta, Asok Ray, Thyagaraju Damarla. Symbolic Dynamic Filtering of Seismic Sensors for Target Detection and Classification, 2011 American Control Conference. 01-JUL-11, . . . ,

- 08/11/2011 63.00 Srikanth Hariharan, Chatschik Bisdikian, Lance M. Kaplan, Tien Pham. QoI-based Resource Allocation for Multi-Target Tracking in Energy Constrained Sensor Networks, IEEE Fusion, July 2011. 05-JUL-11, . . . ,
- 08/11/2011 64.00 Behetash Babadi, Vahid Tarokh. Regularized Recursive Least Squares for Anomaly Detection in Sparse Channel Tracking Applications, 9th Annual IEEE Consumer Communications and Networking Conference (CCNC'11). 02-NOV-11, . . . ,
- 08/11/2011 66.00 Alex Beutel, Thomas Mølhave, Pankaj K. Agarwal, Arnold P. Boedihardjo, James A. Shine. Natural Neighbor Interpolation on a 3D Grid using a GPU, 19th SIGSPATIAL International Conference on Advances in Geographic Information Systems (ACM GIS '11). 01-NOV-11, . . . ,
- 08/14/2012 05.00 Pankaj K. Agarwal, Jun Yang, Albert Yu. Processing and Notifying Range Top-k Subscriptions, 2012 IEEE International Conference on Data Engineering (ICDE 2012). 01-APR-12, Arlington, VA, USA. :

TOTAL: 59

(d) Manuscripts

<u>Received</u>	<u>Paper</u>
07/18/2013 47.00	Soheil Bahrapour, Asok Ray, Soumalya Sarkar, Thyagaraju Damarla, Nasser M. Nasrabadi. Performance Comparison of Feature Extraction Algorithms for Target Detection and Classification, Pattern Recognition Letters (07 2013)
07/23/2012 92.00	Zhoujia Mao, Can Emre Koksal, Ness B. Shroff. Near Optimal Power and Rate Control of Multi-Hop Sensor Networks With Energy Replenishment: Basic Limitations With Finite Energy and Data Storage, IEEE Transactions on Automatic Control (04 2012)
07/23/2012 85.00	Patrick Adenis, Yicheng Wen, Asok Ray. An inner product space on irreducible and synchronizable probabilistic finite state automata, Mathematics of Control Signals and Systems (01 2012)
07/23/2012 88.00	G. Mallapragada, A. Ray, Xin Jin. Symbolic Dynamic Filtering and Language Measure for Behavior Identification of Mobile Robots, IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics) (06 2012)
07/23/2012 89.00	Xin Jin, Soumalya Sarkar, Asok Ray, Shalabh Gupta, Thyagaraju Damarla. Target Detection and Classification Using Seismic and PIR Sensors, IEEE Sensors Journal (06 2012)
07/23/2012 86.00	Soumik Sarkar, Kushal Mukherjee, Xin Jin, Dheeraj S. Singh, Asok Ray. Optimization of symbolic feature extraction for pattern classification, Signal Processing (03 2012)
07/23/2012 87.00	Devesh K. Jha, Dheeraj S. Singh, S. Gupta, A. Ray. Fractal analysis of crack initiation in polycrystalline alloys using surface interferometry, EPL (Europhysics Letters) (05 2012)
07/23/2012 90.00	Soumik Sarkar, Kushal Mukherjee, Asok Ray, Abhishek Srivastav, Thomas A. Wettergren. Statistical Mechanics-Inspired Modeling of Heterogeneous Packet Transmission in Communication Networks, IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics) (08 2012)
07/23/2012 91.00	Asok Ray, Kushal Mukherjee, Subhadeep Chakraborty, Devesh K. Jha. Classification of Two-phase Flow Patterns by Ultrasonic Sensing*, Journal of Dynamic Systems Measurement and Control (12 2011)
07/24/2012 00.00	Pankaj K. Agarwal, Peyman Afshani, Lars Arge, Kasper Green Larsen, Jeff M. Phillips. (Approximate) Uncertain Skylines, Theory of Computing Systems (02 2012)
07/27/2012 94.00	Vahid Tarokh, Behdash Babadi. Distributed Dynamic Spectrum Allocation for Secondary Users in a Vertical Spectrum Sharing Scenario, IEICE TRANSACTIONS on Communications Vol.E95-B No.4 pp.1044-1055 (04 2012)
08/07/2012 14.00	Yicheng Wen, Asok Ray. Vector space formulation of probabilistic finite state automata, Journal of Computer and System Sciences (07 2012)
08/14/2012 93.00	Jiho Ryu, Changhee Joo, Ted "Taekyoung" Kwon, Ness B. Shroff, Yanghee Choi. DSS: Distributed SINR based Scheduling Algorithm for Multi-hop Wireless Networks, IEEE Transactions on Mobile Computing (04 2012)

TOTAL: 13

Number of Manuscripts:

Books

Received Book

08/11/2011 81.00 Shashi Phoha, Doina Bein, Yicheng Wen, Bharat B. Madan, Asok Ray. Dynamically Adaptive Multi-modal Sensor Fusion in Urban Environments, : , (08 2011)

08/11/2011 82.00 Behtash Babadi, Doina Bein, Bharat B. Madan, Shashi Phoha, Vahid Tarokh, Yicheng Wen. Improving Target Localization and Tracking by Dynamically Prioritized Frequency Band Allocation for Wireless Sensor Networks in Urban Environments, : , (12 2011)

08/22/2012 23.00 Xin Jin, Shalabh Gupta, Kushal Mukherjee, Asok Ray. Symbolic Dynamic Filtering for Pattern Recognition in Distributed Sensor Networks, Boca Raton, Florida: Chapman & Hall / CRC, (09 2012)

TOTAL: 3

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

2008

Dr. Ness Shroff recipient of the best paper award for IEEE INFOCOM 2008.

Dr. Pankaj K. Agarwal: R.J.R. Nabisco Professor of Computer Science and Mathematics.

2009

Best Paper Presentation in the Session by S. Sarkar, Graduate Student S. Sarkar, C. Rao and A. Ray, "Estimation of Multiple Faults in Aircraft Gas-turbine Engines," American Control Conference, St. Louis, MO, June 2009.

Best Paper Presentation in the Session by S. Sarkar, Graduate Student S. Sarkar, K. Mukherjee, A. Srivastav and A. Ray, "Understanding phase transition in communication networks to enable robust and resilient control," American Control Conference, St. Louis, MO, June 2009.

Best Paper Presentation in the Session by Dr. I. Chattopadhyay, Research Associate I. Chattopadhyay and A. Ray, "Generalization of v^* Path Planning For Accommodation of Amortized Dynamic Uncertainties in Plan Execution," American Control Conference, St. Louis, MO, June 2009

Best Paper Presentation in the Session by Dr. I. Chattopadhyay, Research Associate I. Chattopadhyay and A. Ray, "Supervised Self-organization of Large Homogeneous Swarms Using Ergodic Projections of Markov Chains," American Control Conference, St. Louis, MO, June 2009.

Best Paper Presentation in the Session by Dr. I. Chattopadhyay, Research Associate W. Lu, I. Chattopadhyay, G. Mallapragada and A. Ray, "A Real time Implementable All-Pair Dynamic Planning Algorithm for Robot Navigation Based on the Renormalized Measure of Probabilistic Regular Languages," American Control Conference, St. Louis, MO, June 2009.

Dr. Ness Shroff Guest Chaired Professor of Wireless Communications and Networking, Dept. of Electronic Engineering, Tsinghua University, Beijing, China (April 2009 - April 2012).

Dr. Ness Shroff Distinguished Invited Speaker, IEEE 17TH International Conference on Computer Communication and Networks (ICCCN), Aug. 2008.

Dr. Ness Shroff Invited Panel member on "What are the hot topics in Networking?" IEEE INFOCOM 2009, April 2009, Rio De Janeiro, Brazil.

Dr. Ness Shroff Invited Panel member on "Future of Multi-hopping: from Theory to Practice," ACM Mobihoc 2009, May, New Orleans.

Dr. Pankaj K. Agarwal Best paper award: Efficient sensor placement for surveillance problems, in Fifth IEEE International Conference on Distributed Computing in Sensor Systems, 2009.

Dr. Roger Brockett recipient of the 2009 IEEE Leon Kirchmeyer Award for Graduate Education.

Alan O'Connor won the "Zhang Si-Ying (CCDC) Outstanding Youth Paper Award", for his paper at the 21st Chinese Control and Decision Conference.

2010

Behdash Babadi won the GSAS Fellowship Award, which is "awarded to one Phd student in each department for outstanding academic performance".

Ness Shroff:Keynote address on " Analytical Foundations for the Efficient, Robust, and Scalable Design of Multi-hop Wireless Networks, " MSN 2009, Yu Wi Mountain, China, December 2010.

Ness Shroff:Chaired Professor (Guest), Dept. of Electronic Engineering, Tsinghua University, Beijing, China 2009-2012. Distinguished Seminar Speaker, Illinois Institute of Technology, April 2010.

Pankaj Agarwal:Amar S. Gupta Distinguished Professor, IIT Delhi, India

2011

Pankaj K. Agarwal, Best paper award "Natural Neighbor Interpolation Based Grid DEM Construction Using a GPU," Nineteenth ACM Symposium on Advances in Geographic Information Systems, 2010.

Ness B. Shroff, Keynote Address, "Beyond Stability: Open Problems in Multi-hop Wireless Networks," IEEE WiOPT 2011, Princeton, New Jersey, May 2011.

Roger Brockett, McDonald Mentoring Award

Vahid Tarokh, Guggenheim Fellowship

Behtash Babadi, Harvard University Graduate School of Arts and Sciences Fellowship Award

2012

Asok Ray won the 2012 Henry M. Paynter Outstanding Investigator Award

Vahid Tarokh won the 2012 IEEE COMSOC TCCN (Technical Committee of Cognitive Networks) Publication award.

X. Jin , S. Sarkar, A. Ray, S. Gupta, and T. Damarla, "Target Detection and Classification Using Seismic and PIR Sensors", IEEE Sensors Journal, Vol. 12, No. 6, June 2012, top 25 most downloaded Sensors Journal papers in the month of May, 2012

Best student paper award for the paper "Low-complexity Optimal Scheduling Over Correlated Fading Channels with ARQ Feedback," by W. Ouyang, A. Eryilmaz, N. B. Shroff, IEEE 10th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOPT'12), Paderborn, Germany, May 2012.

The paper "Mergeable summaries," by P. K. Agarwal, G. Cormode, Z. Huang, J. M. Phillips, Z. Wei, and K. Yi, in Proceedings 31st Annual Symposium on Principles of Database Systems, 2012, 23-34 was invited to the special issue of the conference.

Best paper presentation in American Control Conference, Montreal, Canada by Dr. Kushal Mukherjee (Postdoctoral Scholar)

Best paper presentation in American Control Conference, Montreal, Canada by Mr. Soumalya Sarkar (Graduate Student)

2013

Vahid Tarokh won the 2013 IEEE Eric E. Sumner Award

Ness Shroff won runner-up paper award at IEEE INFOCOM 2013 (1 best paper and 2 runner up papers were selected out of 1600 submitted papers)

Ness Shroff Honorary Guest chaired professor at Shanghai Jiaotong University in China, 2012

Shengbo Chen (OSU) Best student paper award at IEEE WiOPT, May 2013.

Pankaj Agarwal receiving honorary PhD Degree at Aarhus University, Denmark

Roger Brockett was named a Fellow of the American Mathematical Society

Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:..... 0.00

Names of Personnel receiving masters degrees

<u>NAME</u>
Total Number:

Names of personnel receiving PHDs

<u>NAME</u>
Total Number:

Names of other research staff

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Note that the lists provided for subcontracts and supported faculty, post-docs and students refer to the MURI's last year only. For complete lists covering the six-year MURI program, please refer to previous reports. Also attached is a list covering all student, faculty and staff associated with the project over the project years.

Last year's scientific and technical progress can be summarized by the following, most recent publications. The full extent of the scientific contribution including a complete list of publications over the course of the six-year MURI program can also be found in previous reports.

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Pankaj K. Agarwal, Swaminathan Sankararaman, Thomas Mølhave, Jiangwei Pan, Arnold P. Boedihardjo. Model-driven matching and segmentation of trajectories, the 21st ACM SIGSPATIAL International Conference. 05-NOV-13, Orlando, Florida.

Papers published in peer-reviewed journals:

Siddharth Sonti, Eric Keller, Joseph Horn, Asok Ray. Stability Monitoring of Rotorcraft Systems: A Dynamic Data-Driven Approach, *Journal of Dynamic Systems, Measurement, and Control*, (01 2014): 0. doi: 10.1115/1.4025988

Kushal Mukherjee, Asok Ray. State splitting and merging in probabilistic finite state automata for signal representation and analysis, *Signal Processing*, (11 2014): 105. doi: 10.1016/j.sigpro.2014.03.045

Xin Jin, Asok Ray. Navigation of autonomous vehicles for oil spill cleaning in dynamic and uncertain environments, *International Journal of Control*, (04 2014): 787. doi: 10.1080/00207179.2013.858829

Technology Transfer

Technology has been transitioned to DoD projects, NASA and Industry.

The transitioning of technology developed in the past years into new areas and into products of relevance to DoD applications, while still producing relevant theoretical results in wireless sensor network communication and large sensor data management.

Technology transition:

- Hierarchical sensor data fusion: we have proposed the use of a sequential decision tree for a multi-agent hybrid dynamic system and demonstrated the superiority of Nonlinear Symbolic Dynamic Filtering (SDF) algorithms for hierarchical sensor data fusion, using data collected in Army Research Lab/DHS experiments with static seismic and PIR sensors.

- Transferring the technologies of contextual and value based fusion from the MURI: We started working on a prototyped unmanned sensor system that will use the transformative advances in computational modeling, instrumentation and control developed in the MURI to incorporate a Dynamic Data Driven Adaptation (DDDA) of a complex distributed sensor system. The recent grant from AFOSR,

“Dynamic Data Driven Machine Perception and Learning for Border Control” will bring in the following major innovations to current state-of-the-art: (i) DDDA via embedded software agents who make sensor network control, adaptation and collaboration decisions based on the contextual information value of the competing data provided by different multi-modal sensors, (ii) DDDA of higher levels of the sensor data fusion framework using dynamic adaptation decisions made by the software agents, (iii) Unsupervised and supervised machine learning, reinforcement learning and transfer learning techniques to acquire and reuse knowledge for dealing with different operational contexts, and (iv) Use of robust sensor data fusion algorithms based on the SDF framework that have already been developed as part of our ongoing MURI research.

- Another strand of applications of the fundamental research on computational mechanics in this MURI is in fault detection and crack analysis on aircraft engines. The data-driven fault detection problem is posed as a multiclass pattern classification problem and an optimal solution has been proposed by partitioning the received sensor data in the SDF-based feature extraction setting, while dealing with sensor degradation (e.g., drift and noise).

Publication Numbers per Submitted Report year *	
<u>2008:</u>	
Published in Peer-Reviewed journals:	25
Non Peer-Reviewed Conference:	3
Published in Peer-Reviewed conference:	23
Books:	1
<u>2009:</u>	
Published in Peer-Reviewed journals:	28
Published in Peer-Reviewed conference:	27
Manuscripts:	5
<u>2010:</u>	
Published in Peer-Reviewed journals:	15
Published in Peer-Reviewed conference:	31
Manuscripts:	3
Books:	3
<u>2011:</u>	
Published in Peer-Reviewed journals:	20
Published in Peer-Reviewed conference:	30
Non Peer-Reviewed Conference:	1
Books:	2

*All other publications since 2011 are listed on the current report and generated by the database.

PATENTS SUBMITTED

1. Online monitoring of refractory wall damage in entrained bed slagging gasification systems (Dr. Ray, PSU)
2. Online void fraction measurement in two phase flow systems via nonlinear filtering of ultrasonic signals (Dr. Ray, PSU)
3. Diagnosis and Estimation of Multiple Faults in Aircraft Gas Turbine Engines (Dr. Ray, PSU)
4. Real time Fatigue Damage Monitoring and Remaining Life Estimation via In Situ Ultrasonic Sensing (Dr. Ray, PSU)

Graduate Students

Amit Patel
Alan O'Connor
Srikanth Hariharan
Bo Ji
Jeff Phillips
Shashidhara Ganjugunte
Sugumar Murugesan
Subhadeep Chakraborty
Xin Jin
Patrick Adenis
Evan J Hendrick
Chinmay Rao
Soumalya Sarkar
Devesh Jha
Michael Ferster
Xudong Chen
Omar Shammas
Seunghoon Nam
Hong Tao Wu
Shane Marcks
Raghvendra Sharathkumar
Nurali Virani
Pritthi Chattopadhyay
Manish Gupta
Albert Yu
Shengbo Chen
Sang Joon Kim
Behdash Babadi
Matthew Cuppett
Anthony Cascone
Abhishek Srivastav
Soumik Sarkar
Kushal Mukherjee
Yicheng Wen
Goutham Mallapragada
Zhoujia Mao
Ji Woo Kim
Casey Trail
Sashidhar Gujunte

Faculty

Shalabh Gupta
Changhee Joo
Ishanu Chattopadhyay
Doina Bein
Vahid Tarokh
John Sustersic
Pankaj Agarwal
Asok Ray
Ness Shroff
Bharat Madan
Shashi Phoha
Roger Brockett

Post Doctorates

Xudong Chen
Junichiro Fukuyama
Amar Rasheed
Michael Moore
Sarah Rajtmajer
Eric Keller
Kushal Mukherjee
Abhishek Srivastav
Natasha deVroye
Mai Vu
Esther Ezra
Shalabh Gupta
Ishanu Chattopadhyay

Under Graduates

Andrew Homich
Dennis Kriczky
Philip Swaney
Anna Rish
Zachary Kehs
Mathew Jones
Andrew Harris
Brandon Tricou
Scott Rager

Other Research Staff

Jason Douglas
Kevin Fisher
Pamela Beranty
Eric Grele
John Koch

PHDs awarded

Yicheng Wen
Abhishek Srivastav
Sang Joon Kim
Subhadeep Chakraborty
Goutham Mallapragada
Aparna Subbu
Dheeraj Singh
Xudong Chen
Seunghoon Nam
Shashidhar Ganjungunte
Chinmay Rao
Alan O'Connor
Soumik Sarkar
Srikanth Hariharan
Kushal Mukherjee
Behdash Babadi

Masters Awarded

Steven Brown
Soumik Sarkar
Dheeraj Singh
Jeff Phillips
Kushal Mukherjee
Xin Jin
Patrick Adenis
Amit Patel
Evan Hendrick
Michael Ferster
Omar Shammas