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4. TITLE AND SUBTITLE
Final Report: 5.2 Information Processing & Fusion: Fusion of Statistically Dependent Heterogeneous Information Sources

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W911NF-14-1-0339

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
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6. AUTHORS

5d. PROJECT NUMBER

5e. TASK NUMBER

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7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
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113 Bowne Hall
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13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Pramod Varshney
UU	UU	UU	UU		19b. TELEPHONE NUMBER 315-443-1060

RPPR Final Report
as of 16-Mar-2023

Agency Code: 21XD

Proposal Number: 63915MI **Agreement Number: W911NF-14-1-0339**
INVESTIGATOR(S):

Name: Pramod K. Varshney
Email: varshney@syr.edu
Phone Number: 3154431060
Principal: Y

Organization: **Syracuse University**
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Country: USA
DUNS Number: 002257350 EIN: 150532081
Report Date: 16-Nov-2018 Date Received: 16-Mar-2023
Final Report for Period Beginning 01-Jul-2014 and Ending 16-Aug-2018
Title: 5.2 Information Processing & Fusion: Fusion of Statistically Dependent Heterogeneous Information Sources
Begin Performance Period: 01-Jul-2014 **End Performance Period:** 16-Aug-2018
Report Term: 0-Other
Submitted By: Amy Deppa Email: asdeppa@syr.edu
Phone: (315) 443-9355

Distribution Statement:

STEM Degrees: **STEM Participants:**

Major Goals: The goal of this project was to investigate models, measures and methodologies for the fusion of statistically dependent heterogeneous information for a variety of inference tasks. We intended to understand the various ways in which statistical dependence among sensor measurements affects performance for inference networks and to develop collaboration and fusion methods that exploit statistical dependence to enhance inference performance in benign as well as in adversarial environments.
In most research on distributed inference problems, sensor observations are assumed to be statistically independent or at least conditionally independent for analytical tractability. In real world, however, observations are statistically dependent. One barrier in this area is the inability to accurately model statistical dependence in a form that can be used for information fusion to enhance inference performance. The problem is exacerbated when the information sources are diverse and from different modalities. The second barrier is to define statistical dependence when the marginal distributions are not Gaussian, e.g., they are heavy tailed for example. Finally, dependence models must be scalable in a computationally efficient manner so that they can be employed for a large number of information sources. The significance of the work performed in this project was that it will enable the development of efficient fusion methodologies for dependent heterogeneous data from diverse and multi-modality sources even in adversarial environments.

In most research on distributed inference problems, sensor observations are assumed to be statistically independent or at least conditionally independent for analytical tractability. In real world, however, observations are statistically dependent. One barrier in this area is the inability to accurately model statistical dependence in a form that can be used for information fusion to enhance inference performance. The problem is exacerbated when the information sources are diverse and from different modalities. The second barrier is to define statistical dependence when the marginal distributions are not Gaussian, e.g., they are heavy tailed for example. Finally, dependence models must be scalable in a computationally efficient manner so that they can be employed for a large number of information sources. The significance of the work performed in this project was that it will enable the development of efficient fusion methodologies for dependent heterogeneous data from diverse and multi-modality sources even in adversarial environments.

The main focus of the project was to explore ways to accurately characterize statistical dependence and system diversity followed by the development of computationally efficient approaches that can scale to large systems. Dependence models went beyond the usual second-order measures that only model linear dependence and considered tree-based approaches for scaling. Our work in this direction investigated the use of copula theory and tree structures for this purpose. We looked for other modelling approaches that may involve information theoretic tools as well as look for ways to characterize diversity arising due to heterogeneity and multiple modalities. Game

theoretical tools were also used to develop fusion and collaboration methodologies in the presence of malicious adversaries.

Accomplishments: Please see the attached pdf file.

Training Opportunities: Nothing to Report

Results Dissemination: A number of papers were published and technical talks given. Please see the pdf file for a list of journal publications.

Honors and Awards: Pramod K. Varshney received Doctor of Engineering, honoris causa, from Drexel University, 2014.

Pramod K. Varshney received the ECE Distinguished Alumni Award from the University of Illinois in 2015,

Pramod K. Varshney received the Yaakov Bar-Shalom award for lifetime excellence in Information Fusion by the International Society of Information Fusion, 2018.

Protocol Activity Status:

Technology Transfer: During this period, the PI interacted with a large number of companies and participated in their SBIR/STTR projects. For a list of interactions, please see the annual interim reports.

In addition, collaboration with Army Research Laboratory also took place.

PARTICIPANTS:

Participant Type: Graduate Student (research assistant)
Participant: Prashant Khanduri
Person Months Worked: 15.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Shan Zhang
Person Months Worked: 15.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Swatantra Kafle
Person Months Worked: 15.00 **Funding Support:**
Project Contribution:
National Academy Member: N

ARTICLES:

RPPR Final Report
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE TRANSACTIONS ON Signal Processing
Publication Identifier Type: Publication Identifier:
Volume: 6.3E+001 Issue: 1.1E+001 First Page #: 2790
Date Submitted: Date Published:
Publication Location:
Article Title: Detection of Dependent Heavy-Tailed Signals
Authors:
Keywords: Copula theory, dependence modeling, detection,heavy-tailed signals, heterogeneous sensing, information fusion, sensor fusion.
Abstract: This paper examines the problem of detection of dependent alpha-stable signals. Measurements of several phenomena exhibit non-Gaussian, heavy-tailed behavior in their probability density functions (p.d.f.); we use the class of alpha-stable distributions to characterize these signals. When two sensors make simultaneous measurements of such phenomena, these heavy-tailed realizations are dependent across sensors. The intersensor dependence is modeled using copulas. We consider a two-sided test in the Neyman–Pearson framework and present an asymptotic analysis of the generalized likelihood test (GLRT). Both, nested and non-nested models are considered in the analysis. The performance of the proposed scheme is evaluated numerically on simulated data, as well as indoor seismic data. With appropriately selected models, our results demonstrate that a high probability of detection can be achieved for false alarm probabilities of the order of 10e-4.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE TRANSACTIONS ON Signal Processing
Publication Identifier Type: DOI Publication Identifier: http://dx.doi.org/10.1109/TSP.2015.2508781
Volume: 64 Issue: 7 First Page #: 1854
Date Submitted: 9/14/16 12:00AM Date Published: 4/1/16 12:00PM
Publication Location:
Article Title: A Coalitional Game for Distributed Inference in Sensor Networks With Dependent Observations
Authors: Hao He, Pramod K. Varshney
Keywords: Coalitional game, copula theory, distributed inference, statistical dependence, wireless sensor networks
Abstract: We consider the problem of collaborative inference in a sensor network with heterogeneous and statistically dependent sensor observations. Each sensor aims to maximize its inference performance by forming a coalition with other sensors and sharing information within the coalition. In this paper, the formation of non-overlapping coalitions with statistically dependent sensors is investigated under a communication constraint. We apply a game theoretical approach to fully explore and utilize the information contained in the spatial dependence among sensors to maximize individual sensor performance. Before formulating the distributed inference problem as a coalition formation game, we quantify the gain and loss in forming a coalition by introducing the concepts of diversity gain and redundancy loss for both estimation and detection problems. These definitions, enabled by the statistical theory of copulas, allow us to characterize the influence of statistical dependence among sensors.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE TRANSACTIONS ON Signal Processing
Publication Identifier Type: DOI Publication Identifier: 10.1109/TSP.2015.2450191
Volume: 63 Issue: 19 First Page #: 5250
Date Submitted: 9/14/16 12:00AM Date Published: 10/1/15 12:00PM
Publication Location:
Article Title: Distributed Bayesian Detection in the Presence of Byzantine Data
Authors: Bhavya Kailkhura, Yunghsiang S. Han, Swastik Brahma, Pramod K. Varshney
Keywords: Bayesian detection, Data falsification, Byzantine Data, Probability of error, Distributed detection
Abstract: In this paper, we consider the problem of distributed Bayesian detection in the presence of Byzantines in the network. It is assumed that a fraction of the nodes in the network are compromised and reprogrammed by an adversary to transmit false information to the fusion center (FC) to degrade detection performance. The problem of distributed detection is formulated as a binary hypothesis test at the FC based on 1-bit data sent by the sensors. The expression for minimum attacking power required by the Byzantines to blind the FC is obtained. More specifically, we show that above a certain fraction of Byzantine attackers in the network, the detection scheme becomes completely incapable of utilizing the sensor data for detection. We analyze the problem under different attacking scenarios and derive results for different non-asymptotic cases. It is found that existing asymptotics-based results do not hold under several non-asymptotic scenarios.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Signal Processing Letters
Publication Identifier Type: DOI Publication Identifier: 10.1109/LSP.2016.2601911
Volume: 23 Issue: 10 First Page #: 1484
Date Submitted: 9/14/16 12:00AM Date Published: 10/1/16 8:00AM
Publication Location:
Article Title: Universal Collaboration Strategies for Signal Detection: A Sparse Learning Approach
Authors: Prashant Khanduri, Bhavya Kailkhura, Jayaraman J. Thiagarajan, Pramod K. Varshney
Keywords: Dimensionality reduction, multitask detection, sparse learning, universal collaboration
Abstract: This paper considers the problem of high-dimensional signal detection in a large distributed network whose nodes can collaborate with their one-hop neighboring nodes spatial collaboration). We assume that only a small subset of nodes communicate with the fusion center (FC). We design optimal collaboration strategies which are universal for a class of deterministic signals. By establishing the equivalence between the collaboration strategy design problem and sparse principal component analysis (PCA), we solve the problem efficiently and evaluate the impact of collaboration on detection performance.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Transactions on Signal and Information Processing over Networks
Publication Identifier Type: DOI Publication Identifier: https://doi.org/10.1109/TSIPN.2016.2607119
Volume: 3 Issue: 1 First Page #: 145
Date Submitted: 8/31/17 12:00AM Date Published: 9/8/16 12:00PM
Publication Location:
Article Title: Data Falsification Attacks on Consensus-Based Detection Systems
Authors: Bhavya Kailkhura, Swastik Brahma, Pramod K. Varshney
Keywords: Ad-hoc cognitive radio networks, Byzantines, consensus algorithms, data falsification attacks, distributed detection, spectrum sensing
Abstract: This paper considers the problem of signal detection in distributed networks in the presence of data falsification (Byzantine) attacks. Detection approaches considered in the paper are based on fully distributed consensus algorithms, where all of the nodes exchange information only with their neighbors in the absence of a fusion center. For such networks, we first characterize the negative effect of Byzantines on the steady state and transient detection performance of conventional consensus-based detection algorithms. To avoid performance deterioration, we propose a distributed weighted average consensus algorithm that is robust to Byzantine attacks. We show that, under reasonable assumptions, the global test statistic for detection can be computed locally at each node using our proposed consensus algorithm. We exploit the statistical distribution of the nodes' data to devise techniques for mitigating the influence of data falsifying Byzantines on the distributed detection system.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Transactions on Signal and Information Processing over Networks
Publication Identifier Type: DOI Publication Identifier: https://doi.org/10.1109/TSIPN.2017.2723723
Volume: 4 Issue: 1 First Page #:
Date Submitted: 8/27/18 12:00AM Date Published: 3/1/18 6:00PM
Publication Location:
Article Title: Mitigation of Byzantine Attacks on Distributed Detection Systems using Audit Bits
Authors: Wael Hashlamoun, Swastik Brahma, Pramod K. Varshney
Keywords: Distributed Detection, Byzantine Attacks, Kullback-Leibler Divergence, Game Theory
Abstract: This paper considers the problem of distributed detection in the presence of Byzantines who seek to degrade detection performance by falsifying data. The paper proposes a novel mechanism to mitigate Byzantine attacks by partitioning sensors into groups. Local decisions from sensors in each group are sent to the Fusion Center (FC) via multiple paths, which enable the FC to assess (i.e. to audit) the information that reaches it to improve detection performance. We introduce a weighted Kullback-Leibler Divergence (KLD) metric to measure the detection performance of the Fusion Center (FC) and show that the proposed mechanism is more robust against Byzantine attacks than previously proposed schemes. We prove that, using the proposed mechanism, the FC becomes blind (i.e., no useful information reaches the FC) only if all the nodes in the network are Byzantines. The paper also characterizes optimal Byzantine attacks in the scenario when the FC cannot be made blind.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

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as of 16-Mar-2023

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Transactions on Information Forensics and Security
Publication Identifier Type: DOI Publication Identifier: 10.1109/TIFS.2017.2670531
Volume: 12 Issue: 7 First Page #: 1571
Date Submitted: 8/31/17 12:00AM Date Published: 7/1/17 8:00AM
Publication Location:
Article Title: Local Threshold Design for Target Localization Using Error Correcting Codes in Wireless Sensor Networks in the Presence of Byzantine Attacks
Authors: Chun-Yi Wei, Po-Ning Chen, Yunghsiang S. Han, Pramod K. Varshney
Keywords: Target localization, wireless sensor networks, error correcting codes, byzantines, quantizer design.
Abstract: In this paper, we revisit the received signal strength (RSS)-based target localization technique presented in Vempaty et al., where a simple threshold quantizer was employed to quantize the RSS values prior to sending them to the fusion center. It was shown that the probability of misclassification of the distributed classification fusion using error correcting codes scheme vanishes as the number of sensors tends to infinity. This result was obtained based on an intuitive threshold design at the local sensors, and the question of how much a careful design of local thresholds can help improve the overall performance was not addressed. In this paper, we demonstrate the significance of threshold design for accurate and robust target localization in wireless sensor networks, particularly, when the number of sensors is finite. With this objective, we derive an upper bound on the probability of misclassification as a function of RSS thresholds by using the union inequality.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Transactions on Signal Processing
Publication Identifier Type: DOI Publication Identifier: 10.1109/TSP.2016.2630038
Volume: 65 Issue: 4 First Page #: 1068
Date Submitted: 8/31/17 12:00AM Date Published: 2/1/17 10:00AM
Publication Location:
Article Title: Multi-Object Classification via Crowdsourcing With a Reject Option
Authors: Qunwei Li, Aditya Vempaty, Lav R. Varshney, Pramod K. Varshney
Keywords: Classification, crowdsourcing, distributed inference, information fusion, reject option
Abstract: Consider designing an effective crowdsourcing system for M-ary classification where crowd workers complete simple binary microtasks, which are aggregated to give the final result. We consider the novel scenario where workers have a reject option, so they may skip microtasks they are unable or unwilling to do. For example, in mismatched speech transcription, workers who do not know the language may be unable to respond to microtasks in phonological dimensions outside their categorical perception. We present an aggregation approach using a weighted majority voting rule, where each worker's response is assigned an optimized weight to maximize the crowd's classification performance. We evaluate system performance in both exact and asymptotic forms.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Signal Process. Letters
Publication Identifier Type: DOI Publication Identifier: https://doi.org/10.1109/LSP.2017.2778422
Volume: 25 Issue: 1 First Page #: 125
Date Submitted: 8/27/18 12:00AM Date Published: 1/1/18 10:00AM
Publication Location:
Article Title: On Weak Signal Detection with Compressive Measurements
Authors: K.G. Nagananda, and Pramod K. Varshney
Keywords: Compressive sensing, locally optimum detection (LOD), Pade approximation
Abstract: The problem of weak signal detection in Gaussian noise is addressed in the Neyman–Pearson framework with compressive measurements. A locally optimum detector is first devised assuming that the signal is nonsparse by approximating the test statistic around zero using a Taylor series, which is a good estimate only in a small radius around zero. When the signal is sparse, it is shown that the performance of this test degrades. To improve its performance, a new test is devised by deriving the Pade approximation of the test statistic around zero. Pade approximants estimate functions as the rational quotient of two lower degree polynomials and consistently have a wider radius of convergence than the Taylor series. The performance of the Pade-approximated test is better than its Taylor series counterpart and is comparable to the conventional locally optimum test with uncompressed measurements. Simulation results are presented to support the analytical findings of the work.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 2-Awaiting Publicat
Journal: IEEE Trans. Signal Inf. Process. Netw.
Publication Identifier Type: DOI Publication Identifier: https://doi.org/10.1109/TSIPN.2018.2838038
Volume: Issue: First Page #:
Date Submitted: 8/27/18 12:00AM Date Published:
Publication Location:
Article Title: Joint Sparsity Pattern Recovery with 1-bit Compressive Sensing in Distributed Sensor Networks
Authors: Swatantra Kafle, Vipul Gupta, Bhavya Kailkhura, Thakshila Wimalajeewa, Pramod K. Varshney
Keywords: Compressive sensing, distributed sensor networks, quantization, common sparsity pattern recovery, binary iterative hard thresholding
Abstract: In this paper, we study the problem of joint sparse support recovery with 1-bit quantized compressive measurements in a distributed sensor network. Multiple nodes in the network are assumed to observe sparse signals having the same but unknown sparse support. Each node quantizes its measurement vector element-wise to 1-bit. First, we consider that all the quantized measurements are available at a central fusion center. We derive performance bounds for sparsity pattern recovery using 1-bit quantized measurements from multiple sensors when the maximum likelihood decoder is employed. We further develop two computationally tractable algorithms for joint sparse support recovery in the centralized setting. Second, we consider a decentralized setting where each node transmits 1-bit measurements to its onehop neighbors. We show that even with noisy 1-bit compressed measurements, joint support recovery can be carried out accurately in both centralized and decentralized settings.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Proceedings of the IEEE
Publication Identifier Type: DOI Publication Identifier: https://doi.org/10.1109/JPROC.2018.282885
Volume: 106 Issue: 7 First Page #: 1166
Date Submitted: 8/27/18 12:00AM Date Published: 7/1/18 8:00AM
Publication Location:
Article Title: Received-Signal-Strength-Based Localization in Wireless Sensor Networks
Authors: Ruixin Niu, Aditya Vempaty, Pramod K. Varshney
Keywords: Byzantine attacks; channel-aware estimation; Cramer Rao lower bound (CRLB); localization; quantization; received signal strength (RSS); security; sensor selection; wireless sensor networks
Abstract: In this paper, an overview of recent developments in received-signal-strength (RSS)-based localization in wireless sensor networks is presented. Several important practical issues and their solutions are discussed. To save communication bandwidth and sensor energy, a maximum-likelihood estimator based on quantized data is presented along with its corresponding Cramer Rao lower bound (CRLB) and optimal quantizer design schemes. For further system resource savings, an iterative sensor selection approach is presented to activate only the most informative sensors, by maximizing the mutual information or minimizing the posterior CRLB at each iteration. For a resource constrained WSN with imperfect wireless channels, channel aware target localization is described, where the channel model is incorporated into the localization scheme itself, thereby improving performance without increasing communication overhead.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Signal Processing Letters
Publication Identifier Type: Publication Identifier:
Volume: Issue: First Page #:
Date Submitted: 8/27/18 12:00AM Date Published:
Publication Location:
Article Title: Robustness of the Counting Rule for Distributed Detection in Wireless Sensor Networks
Authors: Abhinav Goel, Adarsh Patel, Kyatsandra G. Nagananda, Pramod K. Varshney
Keywords: Counting rule, distributed detection, energy efficiency, robust sensing, sensitivity.
Abstract: We consider the problem of energy-efficient distributed detection to infer the presence of a target in a wireless sensor network and analyze its robustness to modeling uncertainties. The sensors make noisy observations of the target's signal power, which follows the isotropic power-attenuation model. Binary local decisions of the sensors are transmitted to a fusion center, where a global inference regarding the target's presence is made, based on the counting rule. We consider uncertain knowledge of: 1) the signal decay exponent of the wireless medium; 2) the power attenuation constant; and 3) the distance between the target and the sensors. For a given degree of uncertainty, we show that there exists a limit on the target's signal power below which the distributed detector fails to achieve the desired performance regardless of the number of sensors deployed. Simulation results are presented to determine the level of sensitivity of the detector to uncertainty in these parameters.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Transactions on Signal Processing
Publication Identifier Type: Publication Identifier:
Volume: Issue: First Page #:
Date Submitted: 8/27/18 12:00AM Date Published: 6/15/18 4:00AM
Publication Location:
Article Title: Optimal Sensor Collaboration for Parameter Tracking Using Energy Harvesting Sensors
Authors: Shan Zhang, Sijia Liu, Vinod Sharma, Pramod K. Varshney
Keywords: Wireless sensor networks, parameter tracking, node collaboration, energy harvesting, semidefinite programming
Abstract: In this paper, we design an optimal sensor collaboration strategy among neighboring nodes while tracking a timevarying parameter using wireless sensor networks in the presence of imperfect communication channels. The sensor network is assumed to be self-powered, where sensors are equipped with energy harvesters that replenish energy from the environment. In order to minimize the mean square estimation error of parameter tracking, we propose an online sensor collaboration policy subject to realtime energy harvesting constraints. The proposed energy allocation strategy is computationally light and only relies on the second order statistics of the system parameters. For this, we first consider an offline nonconvex optimization problem, which is solved exactly when using semidefinite programming. Based on the offline solution, we design an online power allocation policy that requires minimal online computation and satisfies the dynamics of energy flow at each sensor.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Wireless Communications Letters
Publication Identifier Type: Publication Identifier:
Volume: Issue: First Page #:
Date Submitted: 8/27/18 12:00AM Date Published: 6/1/18 4:00AM
Publication Location:
Article Title: Target Localization Using Sensor Location Knowledge in Wireless Sensor Networks
Authors: Chun-Yi Wei, Hsuan-Yin Lin, Po-Ning Chen, Yunghsiang S. Han, Pramod K. Varshney
Keywords: Target localization, wireless sensor networks, error correcting codes, byzantines, quantizer design.
Abstract: Incorporating error correcting coding techniques into target localization provides an immediate advantage that existing decoding algorithms can be used to determine which area the target is most likely located in. The important knowledge of exact sensor positions is, however, ignored in these decoding algorithms. This letter revisits the problem and shows that based on the weighted average of sensor positions with binary weightings from local decisions, a newly proposed decoding criterion can achieve a much better accuracy in target localization than the soft- and hard-decision rules particularly when a certain number of sensors are under Byzantine attacks.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: GlobalSIP
Date Received: 30-Aug-2017 Conference Date: 08-Dec-2016 Date Published: 08-Dec-2016
Conference Location: Greater Washington, D.C., USA
Paper Title: Detection Diversity of Spatio-Temporal Data using Pitman's Efficiency for low SNR Regimes
Authors: Prashant Khanduri, Vinod Sharmay, Pramod K. Varshney
Acknowledged Federal Support: **Y**

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as of 16-Mar-2023

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: ICASSP
Date Received: 30-Aug-2017 Conference Date: 05-Mar-2017 Date Published:
Conference Location: New Orleans, LA, USA
Paper Title: Detection with Multimodal Data using Low Dimensional Random Projections
Authors: Thakshila Wimalajeewa, Pramod K. Varshney
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: ICASSP
Date Received: 30-Aug-2017 Conference Date: 05-Mar-2017 Date Published:
Conference Location: New Orleans, LA, USA
Paper Title: A unified diversity measure for distributed inference
Authors: Prashant Khanduri, Aditya Vempaty, Pramod K. Varshney
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Proceedings of the Time Series Workshop at NIPS
Date Received: 30-Aug-2017 Conference Date: 05-Dec-2016 Date Published:
Conference Location: Barcelona, Spain
Paper Title: Influential Node Detection in Implicit Social Networks using Multi-task Gaussian Copula Models
Authors: Qunwei Li, Bhavya Kailkhura, Jayaraman Thiagarajan, Zhenliang Zhang, Pramod Varshney
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 2-Awaiting Publicat
Conference Name: ICASSP
Date Received: Conference Date: 15-Apr-2018 Date Published:
Conference Location: Calgary, Canada
Paper Title: On Sequential Random Distortion Testing of Non-Stationary Processes
Authors: Prashant Khanduri, Dominique Pastor, Vinod Sharma, Proamod K. Varshney
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 3-Accepted
Conference Name: Asilomar Conference on Signals, Systems, and Computers
Date Received: Conference Date: 28-Oct-2018 Date Published:
Conference Location: Pacific Grove, CA
Paper Title: Generalized Approximate Message Passing for Noisy 1-bit Compressed Sensing with side information
Authors: Swatantra Kafle, Thakshila Wimalajeewa, Pramod K. Varshney
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 2-Awaiting Publicat
Conference Name: 21st International Conference of Information Fusion
Date Received: Conference Date: 10-Jul-2018 Date Published:
Conference Location: Cambridge, UK
Paper Title: Online Design of Precoders for High Dimensional Signal Detection in Wireless Sensor Networks
Authors: Prashant Khanduri, Lakshmi N. Theagarajan, Pramod K. Varshney
Acknowledged Federal Support: **Y**

DISSERTATIONS:

RPPR Final Report
as of 16-Mar-2023

Publication Type: Thesis or Dissertation
Institution:
Date Received: 30-Aug-2015 Completion Date:
Title: HYPOTHESIS TESTING USING SPATIALLY DEPENDENT HEAVY-TAILED MULTISENSOR DATA
Authors:
Acknowledged Federal Support:

Publication Type: Thesis or Dissertation
Institution: Syracuse University
Date Received: 15-Sep-2016 Completion Date: 10/31/15 7:19PM
Title: Heterogeneous Sensor Signal Processing for Inference with Nonlinear Dependence
Authors: Hao He
Acknowledged Federal Support: **Y**

Partners

,

I certify that the information in the report is complete and accurate:
Signature: Pramod Kumar Varshney
Signature Date: 3/16/23 11:36AM

Accomplished:

Multimodal Signal Processing: The PI and his research group extended their research on distributed detection to a detection problem when dependence among multimodal data is modeled in a compressed domain where compression is obtained using low dimensional random projections [1]. It was shown that, under certain conditions, detection with multimodal dependent data in the compressed domain with a small number of compressed measurements yields enhanced performance compared to detection with high dimensional data.

Random Distortion Testing: The PI and his research group in collaboration with researchers from IMT Atlantique and Indian Institute of Science developed a robust non-parametric sequential framework to address the problem of Random Distortion Testing (RDT) [2][9]. The properties of the proposed algorithms were studied, and it was shown that the designed algorithms are robust, can control the false alarm and missed detection probabilities under pre-specified levels while making a decision faster on average compared to its fixed sample size counterpart.

Signal Detection/Recovery with Compressive Measurements: The PI and his research group in collaboration with researchers from University of California Berkeley and LLNL studied the problem of joint sparse support recovery with 1-bit quantized compressive measurements in a distributed sensor network [7]. They proposed algorithms for centralized and decentralized systems and showed that recovery can be carried out accurately in both settings. Later in [8], the PI and his research group developed Generalized Approximate Message Passing based algorithms for sparse signal recovery with 1-bit quantized compressive measurements.

Collaboration and Precoding Design for Inference: The PI and his research group in collaboration with researchers from MIT-IBM Watson AI Lab and Indian Institute of Science designed optimal sensor collaboration strategies for parameter tracking using energy harvesting sensors [13]. An online and computationally light collaboration strategy was proposed and was shown to be asymptotically equivalent to the optimal offline solution. In [24], the PI and his research group designed optimal sensor collaboration strategies which are universal for a class of deterministic signals and evaluated the impact of collaboration on detection performance. The PI and his research group in collaboration with a researcher from Indian Institute of Technology Palakkad addressed the problem of precoder design for distributed detection of unknown high dimensional signals [10]. Efficient online linear precoding/compression strategies were proposed, and it was shown that the proposed techniques achieve better detection performance compared to earlier schemes known in literature.

Weak Signal and Distributed Detection: In [6], the PI in collaboration with a researcher from PES University in India considered the problem of weak signal detection in Gaussian noise with compressive measurements. A new test was devised by deriving the Padé approximation of the test statistic around zero. The PI and his research group in collaboration with researchers from PES University in India also considered the problem of energy-efficient distributed detection to infer the presence of a target in a wireless sensor network and analyzed its robustness to modeling uncertainties [12]. It was shown that there exists a limit on the target's signal power below which the distributed detector fails to achieve the desired performance regardless of the number of sensors deployed.

Inference in the Presence of Byzantines and Eavesdroppers: 1) In this work, the PI in collaboration with researchers from Virginia Commonwealth University and IBM Thomas J. Watson Research Center overviewed the recent developments in received-signal-strength (RSS)-based localization in wireless sensor networks [11]. First, several important practical issues and their solutions were discussed and then another practical issue involving the presence of malicious sensors called Byzantines was discussed and mitigation schemes were provided.

2) The PI and his research group considered detection [3][16][18][19][20] and localization [4] [14] problems in the presence of Byzantines. In [3], the problem of distributed detection under the Neyman-Pearson framework was considered. In [18], the problem of distributed detection under the Bayesian framework was considered. Novel robust mechanisms to mitigate Byzantine attacks by partitioning sensors into groups and then using audit bits was proposed. In [19], a distributed weighted average consensus algorithm was proposed in fully distributed networks. In [20], the optimal Byzantine attack strategy was investigated in an arbitrary finite number of hypothesis testing problem where attackers were assumed to be aware of the statistics of local outputs. In [16], the PI and his research group in collaboration with researchers from National Taiwan University of Science and Technology analyzed the non-asymptotic performance of distributed Bayesian detection with Byzantines. The problem under different attacking scenarios was analyzed and closed form expressions for optimal attacking strategies for different non-asymptotic cases was derived. Moreover, the closed form expression for the optimal fusion rule was obtained when the FC has complete knowledge of its opponent's strategies.

3) In [5], the PI in collaboration with researchers from IBM Research and Lawrence Livermore National Laboratories presented a new paradigm for mitigation of Byzantine attacks using coding theory results. The applicability of error-correcting output codes was shown for a wide range of inference problems like classification, localization and estimation. Moreover, the approach was shown to be applicable for crowdsourcing-based inference problems.

4) The PI and his research group considered the design of distributed detection networks in the presence of an eavesdropper [23]. An efficient algorithm to find the optimal LRT threshold was proposed. Furthermore, efficient quantizer designs in the general case of non-i.i.d. received symbols at the FC and Eve were proposed.

Inference in the presence of dependent data: 1) The PI and his research group in collaboration with a researcher from Siemens Research and Technology Center utilized alpha-stable signal models with copula-based dependence models for characterizing dependent heavy-tailed distributions and a detailed analysis of detection performance was presented [15]. The copula-based dependence model was also utilized in [21] to take complex dependence among sensor decisions into account. In [21] the PI and his research group proposed an efficient and computationally light regular vine copula based optimal fusion algorithm and numerical experiments demonstrated the effectiveness of their approach. Another novel model was investigated by the PI and his research group to characterize the property of dependent data [22]. In [22], the capability of compressed sensing to capture statistical properties of uncompressed data was exploited for dependent data fusion.

2) The PI and his research group investigated the different roles played by inter-sensor dependence for inference problems, including both detection and estimation [17]. A coalition formation game for the more generalized distributed inference problem with dependent observations for large heterogeneous sensor networks was formulated and an efficient iterative algorithm based on merge and split operations was developed to solve the coalition formation game.

Target Localization: The PI in collaboration with researchers from National Taipei University, National Chiao-Tung University and National Taiwan University of Science and Technology revisited the received signal strength (RSS) based target localization technique [4]. Based on the notion of person-by-person optimization, an algorithm to determine a set of RSS thresholds that minimize the probability of misclassification upper bound was devised. Later in [14], the authors extended the work and showed better localization performance in the presence of Byzantines when the knowledge of sensor positions is incorporated in the decoding scheme.

Design of a Crowdsourcing System: The PI and his research group using an aggregation approach to design an effective crowdsourcing system for M-ary classification problem [25]. Improved performance compared with conventional majority voting was obtained.

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