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14. ABSTRACT

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a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU	UU		Chien-Fu Wu
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RPPR Final Report

as of 23-Dec-2021

Agency Code: 21XD

Proposal Number: 69808MA

Agreement Number: W911NF-17-1-0007

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Report Date: 20-Aug-2021

Date Received: 22-Dec-2021

Final Report for Period Beginning 21-Nov-2016 and Ending 20-May-2021

Title: Sequential designs for sensitivity testing and computer experiments

Begin Performance Period: 21-Nov-2016

End Performance Period: 20-May-2021

Report Term: 0-Other

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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees:

STEM Participants:

Major Goals: An experimental design is a plan for conducting experiments to extract maximum information from the system under investigation with minimum investment of time and resources. Sequential designs help to further reduce the cost and time by intelligently choosing the experimental settings based on the data from the previous experiments. The major goals of this project are

1. To develop improved methods for sensitivity testing.
2. To develop sequential maximum projection and related experimental designs for computer experiments.

Accomplishments: (i) A comprehensive comparison of sensitivity testing procedures was published in the Journal of Quality Technology.

(ii) A new funnel testing method for webpage optimization was developed and published in the journal Statistical Theory and Related Methods.

(iii) A new method for robust parameter design optimization was published in Technometrics.

(iv) A new method for constructing space-filling designs was developed for computer experiments and is published in Technometrics.

(v) An adaptive RBF-based method was developed for the optimization of expensive functions and is published in the Journal of Global Optimization.

(vi) A new Gaussian process modeling method using transformation and additivity is developed. This paper is published in Technometrics. An R package for implementing transformed additive Gaussian process (TAG) is developed and is made available to the public through CRAN.

(vii) A new method for designing experiments with multiple type of factors was developed and is published in the Journal of Quality Technology. The method can be implemented using the R package MaxPro available to the public through CRAN.

(viii) Worked on a real problem from Army on designing a computer experiment in a highly constrained space. A general method for designing such experiments is published in the journal Statistics and Computing.

(ix) A new method for big and high dimensional data reduction, called projected support points, is developed.

(x) A manuscript is under preparation for designing experiments for identifying important variables with few simulations.

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Training Opportunities: Four PhD students were trained using this grant. Three (Simon Mak, Li-Hsiang Lin, and Arvind Krishna) have graduated. Two are now working as tenure-track assistant professors and one as an assistant professor of instruction in major universities in USA.

Results Dissemination: Nine journal papers were published. Drs Wu and Joseph gave several talks at national and international conferences. Dr. Joseph's 2021 Fall Technical Conference webinar video is posted on the conference website for the public to view.

Honors and Awards: Wu and Joseph received "The Quality Engineering & System Assurance Award" from the QE & SA Directorate of US Army ARDEC, Picatinny Arsenal, May 2017.

Wu received the 2017 Box Medal from ENBIS (European network of business and industrial statistics) and delivered his keynote speech in September in Naples, Italy.

The Su-Wu (2017) paper, which was supported by this ARO grant, won the 2018 Brumbaugh Award from the American Society of Quality (ASQ) for "making the largest single contribution to the industrial application of quality control", among the papers published in 2017 in ALL the journals sponsored by the ASQ.

Wu received the Statistician of the Year (SOY) Award from the Chicago Chapter of the American Statistical Association in 2018 and delivered his award lecture in October of 2018 in Chicago.

Mak, Joseph, and Wu along with their collaborators received the "Statistics in Physical & Engineering Sciences Award" from the American Statistical Association in July-August 2019.

Joseph and Wu along with some of their former students and collaborators at the Procter & Gamble Company, Cincinnati, OH, received the "SPAIG Award" from the American Statistical Association in August 2020.

Wu received the "Class of 1934 Distinguished Professor Award" from Georgia Tech in May 2020, which is the highest honor given to a faculty member at Georgia Tech.

Joseph is elected as a Fellow of the American Society for Quality in 2020.

Wu received the "Monie A. Ferst Award" from Sigma Xi in May 2020, which is a prestigious National-level award. A conference on this Award was organized at Georgia Tech in November 2021.

Joseph received Lloyd S. Nelson Award from the American Society for Quality, which recognizes the paper appearing in the Journal of Quality Technology's 2020 volume with the "greatest immediate impact to practitioners."

Protocol Activity Status:

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Technology Transfer: Professors Wu and Joseph visited the QE&SA Reliability Management Branch, US Army RDECOM ARDEC at Picatinny Arsenal on May 18, 2017. They gave a seminar, which was attended by the army lab personnel from various departments. Professor Wu's talk was on Surrogate modeling of finite element simulations and the uncertainty quantification of a rocket engine design. Professor Joseph's talk was on experimental design, support points, and model calibration. After the seminar Professors Wu and Joseph had a discussion with Doug Ray's group on several projects. Doug Ray mentioned to them that the 3pod developed by Prof. Wu and MaxPro design developed by Prof. Joseph are widely used in the army lab for sensitivity testing and computer simulations, respectively.

Professor Joseph collaborated with Douglas Ray and his team on several occasions for designing simulation experiments. R codes for generating experimental designs on highly constrained space was sent to their team. A paper motivated by an Army problem was published jointly with Ray in Statistics and Computing (Huang, Joseph, and Ray 2021). Another paper with Ray, again motivated by an Army problem, is under preparation.

Roediger (2018) from ARDEC has written an R package called "gonogo", which is further discussed in the review paper by Ray and Roediger (2018). Because the package cannot be posted in a website in the military lab and given that it has no classified information, Professor Wu agreed to post the R package on his Georgia Tech webpage. See <https://www2.isye.gatech.edu/jeffwu/sensitivitytesting/>.

Huang, C., Joseph, V. R., and Ray, D. M. (2021). "Constrained Minimum Energy Designs". Statistics and Computing, 31. <https://doi.org/10.1007/s11222-021-10054-2>

Ray, D. M. and Roediger, P. A. (2018). Adaptive testing of DoD systems with binary response. CHANCE. Preprint.

Roediger, P. (2018). Gonogo: An R implementation of test methods to perform, analyze and simulate sensitivity experiments. Contractor Report AREIS-CR-18007, U.S. Army ARDEC, Picatinny Arsenal, NJ.

PARTICIPANTS:

Participant Type: PD/PI

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Person Months Worked: 4.00

Project Contribution:

National Academy Member: Y

Funding Support:

Participant Type: Co PD/PI

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Person Months Worked: 5.00

Project Contribution:

National Academy Member: N

Funding Support:

Participant Type: Graduate Student (research assistant)

Participant: Simon Mak

Person Months Worked: 15.00

Project Contribution:

National Academy Member: N

Funding Support:

Participant Type: Graduate Student (research assistant)

Participant: L-Hsiang Lin

Person Months Worked: 7.00

Project Contribution:

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Journal: Annals of the Institute of Statistical Mathematics

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Volume: 70

Issue: 2

First Page #: 249

Date Submitted: 8/30/18 12:00AM

Date Published:

Publication Location: Japan

Article Title: A fresh look at effect aliasing and interactions: some new wine in old bottles

Authors: C. F. Jeff Wu

Keywords: Conditional main effects, Γ Fractional factorial designs, Γ Nonregular designs, Γ Orthogonal arrays

Abstract: Interactions and effect aliasing are among the fundamental concepts in experimental design. In this paper, some new insights and approaches are provided on these subjects. In the literature, the "de-aliasing" of aliased effects is deemed to be impossible. We argue that this "impossibility" can indeed be resolved by employing a new approach which consists of reparametrization of effects and exploitation of effect non-orthogonality. This approach is successfully applied to three classes of designs: regular and nonregular two-level fractional factorial designs, and three-level fractional factorial designs. For reparametrization, the notion of conditional main effects (cme's) is employed for two-level regular designs, while the linear-quadratic system is used for three-level designs. The approach can be extended to general observational data by using a new bi-level variable selection technique based on the cme's.

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Statistical Theory and Related Fields

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Volume: 1

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Date Submitted: 8/29/17 12:00AM

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Publication Location:

Article Title: Funnel Testing in Webpage Optimisation: Representation, Design and Analysis

Authors: Heng Su, C. F. Jeff Wu

Keywords: conversion rate optimization, webgraph, factorial design, design of experiment

Abstract: When optimizing webpages in order to achieve the best conversion rate, the traditional approach is to isolate and analyze them separately through a sequence of experiments. In this paper, we propose a new framework to study a system of webpages simultaneously through the use of directed graph, fractional factorial design and simple optimization algorithm. The illustrative example shows that such complicated web systems can be easily studied and optimized by using the proposed methodology.

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Journal: Technometrics

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Date Submitted: 8/27/19 12:00AM

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Publication Location: United States

Article Title: Space-Filling Designs for Robustness Experiments

Authors: V. Roshan Joseph, Li Gu, Shan Ba, William Myers

Keywords: Experimental design, Gaussian process, Optimal designs, Quality improvement, Robust parameter design, Space-filling designs

Abstract: This article develops new experimental design methods for computer simulations involving noise factors. Most existing methods focus on uniformly distributing the points in the design space, which are not suitable for noise factors because they usually follow non-uniform distributions such as normal distribution. This would suggest placing more points in the regions with high probability mass. However, noise factors also tend to have a smooth relationship with the response and therefore, placing more points towards the tails of the distribution is also useful for accurately estimating the relationship. These two opposing effects make the experimental design methodology a challenging problem. We propose optimal and computationally efficient solutions to this problem and demonstrate their advantages using simulated examples and a real industry example involving a manufacturing packing line.

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Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 4-Under Review

Journal: Journal of the American Statistical Association

Publication Identifier Type:

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Volume:

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Date Submitted: 8/30/18 12:00AM

Date Published:

Publication Location:

Article Title: Projected support points: a new method for high-dimensional data reduction

Authors: Simon Mak, V. Roshan Joseph

Keywords: Data reduction, high-dimensional statistics, experimental design, Quasi-Monte Carlo, kernel learning, MCMC reduction

Abstract: In an era where big and high-dimensional data is readily available, data scientists are inevitably faced with the challenge of reducing this data for expensive downstream computation or analysis. To this end, we present here a new method for reducing high-dimensional big data into a representative point set, called projected support points (PSPs). A key ingredient in our method is the so-called sparsity-inducing (SpIn) kernel, which encourages the preservation of low-dimensional features when reducing high-dimensional data. We begin by introducing a unifying theoretical framework for data reduction, connecting PSPs with fundamental sampling principles from experimental design and Quasi-Monte Carlo. Through this framework, we then derive sparsity conditions under which the curse-of-dimensionality in data reduction can be lifted for our method. Next, we propose two algorithms for one-shot and sequential reduction via PSPs, both of which exploit big data subsampling and majorization-minim

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Date Submitted: 12/22/21 12:00AM Date Published: 8/26/20 12:00PM
Publication Location: United States

Article Title: Designing Computer Experiments with Multiple Types of Factors: The MaxPro Approach

Authors: V. Roshan Joseph, Evren Gul, Shan Ba

Keywords: Space-filling designs, Quantitative factors, Qualitative factors, Latin hypercube designs

Abstract: Computer experiments may involve not only continuous input factors but also nominal factors, discrete numeric factors, and ordinal factors. Most existing literature in designing computer experiments focus only on continuous factors. Some works have further considered nominal factors, but the cases that also contain discrete numeric or ordinal factors are almost overlooked. In this work, we propose a new optimal design criterion that can accommodate all these types of factors. The proposed design is flexible in run size and number of factors, and can also achieve good space-filling properties in the full design space and in all possible low-dimensional projections.

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
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Volume: 61 Issue: First Page #: 545
Date Submitted: 12/22/21 12:00AM Date Published:
Publication Location: United States

Article Title: Analysis-of-Marginal-Tail-Means (ATM): A Robust Method for Discrete Black-Box Optimization

Authors: Simon Mak, C. F. Jeff Wu

Keywords: Analysis-of-marginal-Means, orthogonal arrays, Pick-the-Winner, response surface methodology, robust optimization, tail means

Abstract: This paper presents a novel method, called Analysis-of-marginal-Tail-Means (ATM), for parameter optimization over a large, discrete design space. The key advantage of ATM is that it offers effective and robust optimization performance for both smooth and rugged response surfaces, using only a small number of function evaluations. This method can therefore tackle a wide range of engineering problems, particularly in applications where the performance metric to optimize is black-box and expensive to evaluate.

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Statistics and Computing

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Volume: 31

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Date Submitted: 12/22/21 12:00AM

Date Published: 10/18/21 4:00AM

Publication Location: United Kingdom

Article Title: Constrained Minimum Energy Designs

Authors: Chaofan Huang, V. Roshan Joseph, Douglas M. Ray

Keywords: Computer experiment, Experimental design, Space-filling designs, Sequential Monte Carlo

Abstract: Space-filling designs are important in computer experiments, which are critical for building a cheap surrogate model that adequately approximates an expensive computer code. Many design construction techniques in the existing literature are only applicable for rectangular bounded space, but in real world applications, the input space can often be non-rectangular because of constraints on the input variables. One solution to generate designs in a constrained space is to first generate uniformly distributed samples in the feasible region, and then use them as the candidate set to construct the designs. Sequentially Constrained Monte Carlo (SCMC) is the state-of-the-art technique for candidate generation, but it still requires large number of constraint evaluations, which is problematic especially when the constraints are expensive to evaluate. Thus, to reduce constraint evaluations and improve efficiency, we propose the Constrained Minimum Energy Design (CoMinED) that utilizes recent adv

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Acknowledged Federal Support: Y

Partners

I certify that the information in the report is complete and accurate:

Signature: Roshan Vengazhiyil Joseph

Signature Date: 12/22/21 1:18PM

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