

E-24-y75
#3

Final Report for Period: 08/2005 - 07/2006

Submitted on: 01/09/2007

Principal Investigator: Tsui, Kwok-Leung .

Award ID: 0100123

Organization: GA Tech Res Corp - GIT

Title:

Robust Design Optimization for Product Platform Design

Project Participants

Senior Personnel

Name: Tsui, Kwok-Leung

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Allen, Janet

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Mistree, Farrokh

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Chen, Victoria

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Kim, Seonghee

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Seonghee Kim involved in the project by working on joint research with the PI, Dr. Kwok-Leung Tsui, on statistical process control research. They also jointly supervised a ph.d. student, Yongro Park, in the SPC area. They have finished and submitted two joint papers.

Post-doc

Graduate Student

Name: Murphy, Terrence

Worked for more than 160 Hours: Yes

Contribution to Project:

Mr. Murphy's dissertation research is being partially funded by this NSF grant. During this past year, his efforts have been focused on a thorough literature review of Statistical Robust Design. He also contributed slides for our project's presentation at the 2002 NSF Grantees' Conference.

Name: Lin, Yao

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Panchal, Jitesh

Worked for more than 160 Hours: Yes

Contribution to Project:

Jitesh expertise is in computer-supported collaborative design so he has helped with the problem of integrating and understanding the software.

Name: Wang, Shuchun

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Batur, Demet

Worked for more than 160 Hours: No

Contribution to Project:

Demet Batur involved the research in one summer on the SPC problems with monitoring variance.

Name: Han, Sungwan

Worked for more than 160 Hours: No

Contribution to Project:

Sungwan Han was supported for one summer to work on the SPC problems with EWMA charts.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Professor Russell Barton at the Pennsylvania State University has collaborated with PI Kwok Tsui and co-PIs Janet Allen and Victoria Chen on a review paper on methods for Computer Experiments (to appear in the Handbook of Statistics). A second review paper invited by the Journal of Quality Technology is the product of a collaboration between Professors Barton, Tsui, and Chen and Dr. Martin Meckesheimer of The Boeing Company.

Dr. Patrick Koch of Engineous Software, Inc. has assisted us with the use of the iSIGHT software in our work.

Dr. Cristiano Cervellera of the National Research Council of Italy has collaborated with Victoria Chen in a study comparing neural networks and multivariate adaptive regression splines. Their paper is currently under review with the journal Technometrics.

Professor Julia Tsai of Purdue University and Professors Eva Lee and Ellis Johnson in Georgia Tech's School of Industrial and Systems Engineering have collaborated with Victoria Chen on a parallel computing implementation of multivariate adaptive regression splines. Their paper is currently under review with the Informs Journal on Computing.

We have discussed aspects of kriging with Professor J.C.P. Kleinene of Tilburg University, The Netherlands.

Professor Wei Jiang of Stevens Institute of Technology involved in research of process control and data mining.

Activities and Findings

Research and Education Activities:

Research:

(1) Two review papers on Computer Experiments: Chen, Tsui, Barton, and Allen (2003) to appear in the Handbook of Statistics; Chen, Tsui, Barton, and Meckesheimer (2005) accepted by IIE Transactions.

(2) A review paper on statistical methods for optimal design of products with multiple response characteristics by Murphy, Tsui and Allen has been published in Research in Engineering Design. Another paper on diagnosing location and dispersion effect in multivariate SPC was submitted to Journal of Quality Technology. This forms the foundation for Terry Murphy's PhD dissertation. Terry successfully defended his thesis in December, 2004.

(3) We have developed a systematic yet flexible method in which various metamodeling techniques are utilized in building a series of appropriate metamodels for robust design space exploration in accordance with the change in information quality along the design timeline in the early stages of design. Development of the method will be accomplished by (i) studying measures for metamodel validation with additional points, (ii) developing methods for sequential experimental design based on information theory and using the iSIGHT software to implement the methodology, (iii) developing methods for design space reduction by screening factors and reducing factor ranges, and (iv) developing methods for design space definition and shift. Testing and verification of the approach will be based on one- or multi-variable functions and industrial examples.

The theoretical result and application result have been submitted and published in Technometrics and Research in Engineering Design, respectively. This forms the foundation for Yao Lin's PhD dissertation. Yao successfully defended his thesis in August, 2004.

(4) We have investigated process control and data mining methods for engineering design and manufacturing applications. We compared and made recommendations on the latest process control and monitoring methods for correlated processes and processes with multiple characteristics. We identified appropriate data mining algorithms and techniques for improving product design and manufacturing processes. The results have been submitted and accepted for publications in Handbooks in Statistics.

(5) We have developed a methodology for integrated design of products and design processes. The methodology would facilitate computer-based support for modeling existing and new design processes using reusable building blocks. We will implement the system by including the meta modeling and sequential design algorithms developed from our project. The forms parts of Jitesh Panchal's thesis. He has passed his ph.d proposal and submitted papers to Research in Engineering Design.

(6) We have developed new statistical modeling and analysis algorithms for robust design optimization. We are investigating multivariate quality loss and utility functions for measuring the quality performance based on multiple characteristics. This forms parts of Shuchun Wang's thesis. She has passed her comprehensive examination and had finished his ph.d. degree in summer 2006.

Findings:

(1) Through the review on computer experiments, we acquired a solid understanding of the metamodeling options for our robust design approach.

(2) Terry Murphy have quantified how well the covariance and bias components of multivariate expected loss are approximated by a subset of the response principal components. We have developed a new class of principle components based on loss functions and decomposed them into location and dispersion measures. These tools help engineers better understand and diagnose problems for quality improvement.

(3) We identified accessible software for generating experimental designs for metamodeling: orthogonal array (OAs), Latin hypercube (LH) hybrid OA-LH, Hammersley Sequence Sampling (HSS), Uniform. We have tested the software for OAs, LHs, OA-LHs.

(4) We identified accessible software fitting metamodels: response surface methodology (RSM), kriging, multivariate adaptive regression splines (MARS), artificial neural networks (ANNs). We have tested the software for all four methods. In addition, we have developed a parallel computing implementation of MARS.

(5) We determined that the iSIGHT software could be used as a part of an integrating environment, X-DPR, to compare the various types of software and experimental designs. We have also explored several problems which may be used as case studies. Murphy's expected multivariate loss approximation is currently being implemented within X-DPR for comparison against other statistical and engineering objective functions.

(6) Yao Lin has focused on sequential exploration of the design space. In order to accomplish this, he proposes to investigate how a metamodel may be validated with deterministic computer experiments.

He is working to determine the best way to design sequential computer experiments (how to select data and validation points sequentially) in a fixed design space to get an accurate metamodel.

He has found that:

1. Additional validation points are essential in validating the accuracy of a metamodel with computer experiments.
2. Information from previous metamodels (previous data points) and metamodel validation (previous validation points) can be used to identify

new data points in regions where there is large uncertainty.

3. Entropy optimization (from information theory) is a useful tool in analyzing the information uncertainty in experiments, and helps in allocating new data and validation points in sequential experimental design.

(7) We have identified appropriate process control and data mining algorithms for design optimization and process improvement. These algorithms have also been shown to have broad applications in both manufacturing and service applications.

(8) Jitesh Panchal has developed a methodology for integrated design of products and design processes. The methodology would facilitate computer-based support for modeling existing and new design processes using reusable building blocks. The meta modeling and sequential design algorithms developed by our project will be implemented in the system.

(9) The comparison of neural networks and multivariate adaptive regression splines for two stochastic dynamic programming applications indicated that they are both good choices. In addition, it was noted that neural networks tended to perform better with orthogonal array-Latin hypercube hybrid designs than with pure orthogonal array designs. In addition, the space-filling quality of the designs has an effect, with potentially poor results using designs that were judged to have poorer spacing.

(10) The automatic stopping rule implementation of multivariate adaptive regression splines automatically terminates the algorithm when the fit ceases to improve. This approach is significantly more efficient and effective than the original approach of overfitting with too many basis functions and then pruning unnecessary basis functions. The robust implementation of multivariate adaptive regression splines yielded improved fit by giving priority to lower-order basis functions. Finally, the parallel computing implementation of multivariate adaptive regression splines yielded good speedup.

Training and Development:

During the course of this grant, the graduate students Terry Murphy and Yao Lin had passed their PhD qualifying examinations. Both Terry Murphy and Yao Lin have submitted their dissertation proposals on topics stemming from this proposal. Both of them have successfully defended their thesis in 2004.

Terry Murphy has had experience teaching the Quality Control course for undergraduate students.

Jitesh Panchal has completed his MS. He has also taken and passed his PhD qualifiers. He has also submitted and passed his ph.d proposal in Integrated Design of Products and Design Processes in 2004.

Shuchun Wang has completed her MS. She has also taken and passed her PhD comprehensive exam. She has passed her ph.d proposal and successfully defended her thesis in summer 2006.

Outreach Activities:

Farrokh Mistree was a co-general chair of AIAA's 2002 Multidisciplinary Analysis and Optimization (MA&O) Symposium held in Atlanta in September. Janet Allen served as a superchair to coordinate reviews for the MA&O Symposium in the area of uncertainty. She also served as a review coordinator for the ASME Design Automation Conference, ASME Design Theory and Methodology Conference and WETICE 2002 and 2003.

Kwok-Leung Tsui was the co-chair of a cluster of invited sessions in data mining for both the 2002 INFORMS annual conference at San Jose and the 2003 INFORMS annual conference at Atlanta, GA. In 2003 Kwok Tsui and Victoria Chen founded the new Section in Data Mining within the INFORMS society. Kwok served as the first founding chair of the Section and Victoria was the chair elected in 2005.

Victoria was also chair of the cluster of sponsored sessions in data mining for both the 2004 and 2005 INFORMS annual conferences.

Journal Publications

Victoria Chen, Kwok Tsui, Russell Barton, Martin Meckesheimer, "Design, Modeling, and Applications of Computer Experiments", IIE Transactions, p. , vol. , (2005). Accepted

Kulkarni, R., Rosen, D., Allen, J.K. and Mistree, F., "An Information Model for Finding and Integrating Distributed Resources for Engineering Design-Manufacture Processes", ASME Journal of Computing and Information Science in Engineering, p. , vol. , (). Submitted

- Cristiano Cervellera, Victoria Chen, and Wen, A., "Neural Network and Regression Spline Value Function Approximations for Stochastic Dynamic Programming", *Computer and Operation Research*, p. , vol. , (2005). Accepted
- Julia Tsai, Victoria Chen, Eva Lee, and Ellis Johnson, "Parallelization of the MARS Value Function Approximation in a Decision-Making Framework for Wastewater Treatment", *Inform Journal on Computing*, p. , vol. , (). Submitted
- Lin, Y., Mistree, F., Tsui, K.-L., Allen, J., "Meta Model Validation with Deterministic Computer Experiments", *American Institute of Aeronautics and Astronautics*, p. , vol. , (2004). Accepted
- Jiang, W., Murphy, T., and Tsui, K.-L., "Statistical Methods for Quality and Productivity Improvement", *Handbook in Applied Statistics* (edited by H. Pham), p. , vol. , (2005). Accepted
- Murphy, T., Tsui, K.-L., Allen, J.K., "Compromise Design Settings for Multiple Responses", *American Institute of Aeronautics and Astronautics*, p. , vol. , (2005). Accepted
- Murphy, T. and Tsui, K.-L., "Diagnosing Location and Dispersion in Multivariate SPC with Principle Components", *Journal of Quality Technology*, p. , vol. , (2005). Submitted
- Tsui, K.-L., Chen, V.C.P., Jiang, W., and Aslandogan, A., "Data Mining Methods and Applications", *Handbook of Applied Statistics* (edited by H. Pham), p. , vol. , (2005). Accepted
- Lin, Y., Mistree, F., Allen, J.K., Chen, V.C.P., and Tsui, K.-L., "A Sequential Exploratory Experimental Design Method for Developing Appropriate Metamodels in Engineering Design", *Technometrics*, p. , vol. , (2005). Submitted
- Tsai, J.C.C. and Chen, V.C.P., "Flexible and Robust Implementations of Multivariate Adaptive Regression Splines within a Wastewater Treatment Stochastic Dynamic Program", *Quality and Reliability Engineering International*, p. , vol. , (2005). Accepted
- Panchal, J., Choi, H-J, Allen, J.K., Rosen, D.W., Mistree, F., "A Standardized Engineering Framework for Distributed, Collaborative, Engineering Design", *Journal of Computing and Information Science in Engineering*, p. , vol. , (2005). Accepted
- Panchal, J.H., Fernandez, M.G., Paredis, C.J.J., Allen, J.K., Mistree, F., "Leveraging Design Process Related Intellectual Capital-A Key to Enhancing Enterprise Agility", *Engineering Optimization*, p. , vol. , (). Submitted
- Kim, S.H., Alexopoulos, C., Tsui, K.-L., Wilson, J., "A Distribution Free Tabular CuSum Chart for Auto-correlated Data", *IIE Transactions*, p. , vol. , (). Accepted
- Kim, S.H., Alexopoulos, C., Goldsman, D., Tsui, K.-L., "A New Model Free CuSum Chart for Auto-correlated Data", *Journal of Quality Technology*, p. , vol. , (). Submitted

Books or Other One-time Publications

- Victoria Chen, Kwok Tsui, Russell Barton, Janet Allen, "A Review of Design and Modeling in Computer Experiments", (2003). refereed chapter, Accepted
 Editor(s): C. R. Rao and Ravi Khattree
 Collection: *Handbook in Statistics: Statistics in Industry*
 Bibliography: Vol. 22
- Jitesh Panchal, "Toward a Design Support System for Distributed Product Realization", (2003). Thesis, Published
 Bibliography: MS Thesis, The G.W. Woodruff School of Mechanical Engineering, Georgia Tech, Atlanta, GA 30332-0405
- Terry Murphy, "Multivariate Quality Control Using Loss-Scaled Principal Components", (2004). Thesis, Published
 Bibliography: Ph.D thesis, School of Industrial and Systems Engineering, Georgia Tech

Yao Lin, "An Efficient Robust Concept Exploration Method and Sequential Exploratory Experimental Design", (2004). Thesis, Published Bibliography: Ph.D. thesis, School of Mechanical Engineering, Georgia Tech

Web/Internet Site

Other Specific Products

Product Type:

Software (or netware)

Product Description:

WEB-Based MARS (Multivariate Adaptive Regression Splines)

Sharing Information:

The accessibility of the MARS software on the web facilitates collaboration among the PI's who are geographically separated.

Contributions

Contributions within Discipline:

The two review papers on Computer Experiments (Chen, Tsui, Barton, Allen 2003; Chen, Tsui, Barton, Meckesheimer 2003) are the first attempts for a comprehensive review of the metamodeling area from a statistical perspective. This is important for (1) raising awareness in the statistical community and (2) providing a reference for those working in the area of computer experiments.

The submitted paper by Cervellera and Chen (2002) presents the first comparison of ANNs and MARS in approximating the value function of a continuous-state stochastic dynamic program.

The submitted paper by Tsai, Chen, Lee, and Johnson (2002) provides researchers with a new parallel computing implementation of MARS. This is important to help improve efficiency of the MARS algorithms.

The paper in meta model validation (Lin, Allen, Mistree, and Tsui) presents a case study in engineering design with experimental design and kriging modeling. It illustrates the potential benefits of meta modeling with computer experiments.

The paper in quality and productivity improvement (Jiang, Murphy, and Tsui) describes and compare the latest results in process control and monitoring, and robust parameter design in single and multiple characteristics. It help engeneers understand the strength and weakness of variaous tools and be able to apply appropriate techniques under different situations.

The review paper on static multivariate robust design (Murphy, Tsui, Allen) is a comprehensive review and comparison of the most popular techniques documented in the statistical literature.

The SPC diagnosing paper (Murphy and Tsui) develops new methods to analyze and decompose the location and dispersion effects using new principle componenet methods. It helps engineers on diagnostics and identify causes of problems.

The data mining paper (Tsui, Chen, Jiang, and Aslandogen) describes and explain the latest data mining algorithms and applications in various industries. It identify the opportunities of different data mining algorithms for various engineering applications.

The sequential design paper (Lin, Allen, Mistree, Chen, and Tsui) develops new sequential method for choosing experimental design for optimizing design criteria and prediction capability simultaneously. It provides a practical engineering method for balancing the cost and accuracy of designing and planning experiments.

The two papers on engineering design (Panchal et. al.) facilitate compter-based support for modeling existing and new dcsign processes using reusable building blocks.

Contributions to Other Disciplines:

The two review papers on Computer Experiments (Chen, Tsui, Barton, Allen 2003; Chen, Tsui, Barton, Meckesheimer 2003) presented a

variety of engineering applications (electrical, chemical, mechanical, industrial) to illustrate the wide potential influence of computer experiments in engineering decisions.

Terry Murphy will demonstrate the application of an approximated multivariate loss function on the design of a mechanical engineering product with five correlated responses.

The comparison of ANNs and MARS by Cervellera and Chen (2002) has attracted the attention of researchers in stochastic optimal control, which has primarily limited their work to ANNs.

The statistical work being developed for this grant, i.e., the computer infrastructure and methods of narrowing the design space will be used in another project that Professor Mistree and Dr. Allen are involved in an AFOSR sponsored MURI on Energetic Structural Materials (1606U81).

The data mining algorithms and methods have a broad application base, including manufacturing and service industries. Researchers in statistics, computer scientists, and engineering will benefit from the comparisons and applications of various data mining algorithms.

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Organizational Partners

Any Web/Internet Site

Contributions: To Any Human Resource Development

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering