Research Activity Report **2013.10.31**

Research title		A stochastic approach for the numerical simulations to quantify real physical phenomena and improve design reliability
Visiting researcher	**Name**	Koji Shimoyama
	Affiliation	Institute of Fluid Science, Tohoku University
	Title	Assistant Professor
Visiting institution		Stanford University, USA
Visiting period		April 2012 - March 2013
Host researcher	**Name**	Juan J. Alonso
	Affiliation	Department of Aeronautics and Astronautics, Stanford University
	Title	Associate Professor

Summary of Collaborative Research Activities

Aircrafts and spacecrafts require huge time and cost for their design and development, which involve a lot of prototypes and experiments. Thus, numerical simulations are often substituted for experiments to reduce the time and cost. Numerical simulations should provide an accurate prediction of the physical phenomena that may have a great influence on design performance, and contribute to high reliability to be achieved in actual design.

This study aims to establish a method for the numerical simulations to quantitatively predict real-world physical phenomena related to various uncertain factors. Sampling methods (*e.g.*, Monte Carlo) are simple for uncertainty quantification but not practical due to their huge computational cost. Instead, approximation methods (*e.g.*, polynomial chaos expansion: PCE) are recently employed in uncertainty quantification. However, these methods sometimes induce unphysical oscillations in the response of a simulation solution, as seen in Fig. 1, even if the order of approximation increases for higher accuracy. Therefore, this study constructs the algorithm that stochastically models a solution space based on Kriging theory and dynamically extracts characteristic features (*e.g.*, sensitivity, fit-uncertainty) in the solution space based on discretization error theory.

This algorithm is proposed as a new approximation method for uncertainty quantification, and tested in some problems with different dimensionality and continuity. In all the problems, the proposed method can stabilize the response of a simulation solution without unphysical oscillations, as seen in Fig. 2. In addition, the proposed method can reduce the errors included in solution statistics, as seen in Fig. 3.

In future work, the proposed method will be applied to computational fluid dynamics to enhance the detailed understanding of turbulent flow physics. Then, this method will also be applied to aircraft design optimization to produce an aircraft that can fly robustly in a real-world fluctuating environment.

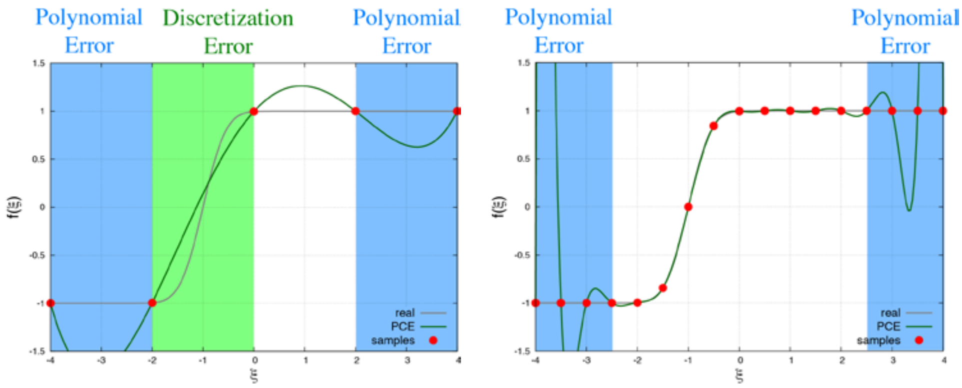

Fig. 1: Responses of a simulation solution approximated by PCE (left: 4^{th}-order, right: 16^{th}-order)

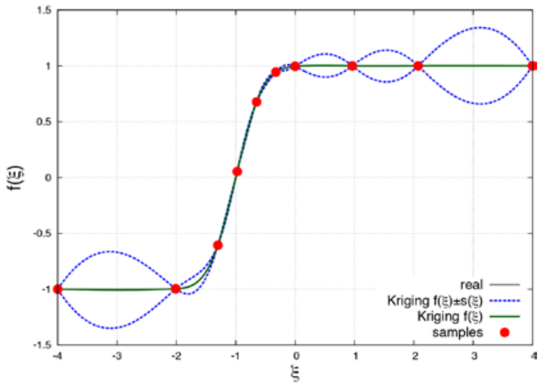

Fig. 2: Response of a simulation solution approximated by the proposed method

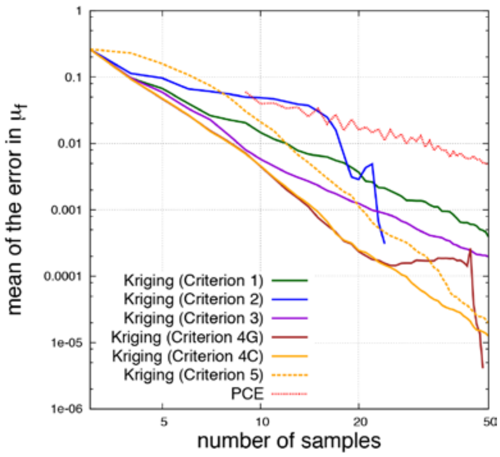

Fig. 3: Errors included in solution statistics estimated by PCE and the proposed method

Publications

1) Journal or conference papers with full paper review (including review papers, invited papers, etc.)

[1] Koji Shimoyama, Soshi Kawai, and Juan J. Alonso: Dynamic Adaptive Sampling Based on Kriging Surrogate Models for Efficient Uncertainty Quantification, *15th AIAA Non-Deterministic Approaches Conference*, (2013), AIAA-2013-1470.

[2] Koji Shimoyama, Soshi Kawai, and Juan J. Alonso: Kriging-Based Dynamic Adaptive Sampling Methods for Uncertainty Quantification (submitted).

2) Conference papers or presentation without full paper review

Not applicable

3) Patent, award, press release etc.

Not applicable