An efficient sampling approach for variance-based sensitivity analysis based on the law of total variance in the successive intervals without overlapping

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1. Introduction

Sensitivity analysis (SA) is to study “how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different source of uncertainty in the model output factors” [1]. Generally, SA can be divided into local SA (LSA) and global SA (GSA). The LSA merely reflects the local information by the partial derivatives of the model output with respect to the model input variable at the nominal points of interest, and the LSA cannot provide the global exploration of the input space. Therefore, there are more studies on the GSA than LSA in recent years as it takes the variation effect of the model input variables into account. Subsequently, several GSA techniques were proposed by some researchers, such as non-parameter model proposed by Helton and Saltelli [1,2], variance based model proposed by Sobol, Iman and so on [3,4], and moment independent model proposed by Borgonovo, Chun and Liu [5,6]. Recently, the GSA also is extended to dynamic models [7–9]. Among these GSA techniques, the variance based GSA attracts more and more attentions because it can directly reflect the contributions of the model input variables to the variance of the model output from the view of the relationship between model output and model inputs.

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At present, various approaches are available to estimate the variance-based GSA which can be divided into two branches: meta-model-based approaches [10–13] and sampling-based approaches [14–22]. Every existing approach has its own advantages and disadvantages. In this paper, the sampling-based approaches are concerned.

Brute force approach is a double-loop integral process which is so inefficient that it cannot be expediently applied in engineering applications. To improve the brute force approach, Sobol and Saltelli proposed a single-loop sampling approach by adding a re-sampling matrix. No matter that Saltelli and co-workers proposed a 'radial sampling' design to make full use of engineering applications. To improve the brute force approach, Sobol and Saltelli proposed a single-loop sampling approach by

$$\text{g}(X) = g_0 + \sum_{1 \leq j \leq n} g_j + \sum_{1 \leq i < j \leq n} g_{ij} + \cdots + g_{12...n}$$

(1)

where $g_0 = E(Y)$, $g_i = E(Y|X_i) - g_0$, $g_j = E(Y|X_i, X_j) - g_i - g_j - g_0$ and so on. Take the variance of Eq. (1), Eq. (2) can be obtained as follows:

$$V(Y) = \sum_{1 \leq i \leq n} V_i + \sum_{1 \leq i < j \leq n} V_{ij} + \cdots + V_{12...n}$$

(2)

where $V(Y)$ is the variance of $Y$, and
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