Prediction of Towing Hook Performance using Support Vector Regression with Sensitivity Analysis*

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Introduction

In order to improve the engineering design, predictive model is needed to identify the performance of the design system. Unlike the commonly used finite element analysis (FEA), predictive models can also be obtained through real experimental data. With appropriate model, it is possible to grasp the properties of the existing design and obtain improved optimal design.

In this research, we propose an analytical scheme to construct predictive model and identify major input parameters that affects to the variation of the response at the same time. The predictive modeling is done through machine learning technique SVR. Distinguishing major variables is done by global sensitivity analysis (GSA) called Sobol`s variance-based method.

Analysis is carried out with Towing-hook data obtained by experiments. The result was confirmed to be a legitimate conclusion by the engineer's prior knowledge.

Material and Methods

- Support Vector Regression (SVR)
  - Machine learning technique proposed by Vapnik which obtains nonlinear-hyper-plane that fits to the response surface. The Hyper-plane and the objective function of SVR are as follows :

$$f(x) =< w, x > + b \quad where \quad w, x \in \mathbb{X}, b \in \mathbb{R}$$

$$minimize \ \frac{\|\boldsymbol{w}\|^2}{2} + \mathrm{C}\sum_{i=1}^{l}(\xi_i + \xi_i^*)$$

$$\text{subject to} \begin{cases} \mathrm{y}_i - < w, x > - b & \leq \varepsilon + \xi_i \\ < w, x > + b - \mathrm{y}_i & \leq \varepsilon + \xi_i^* \\ \xi_i, \xi_i^* & \geq 0 \end{cases}.$$

- GSA and Sobol`s variance-based method
  - GSA is an analysis of how sensitive changes in response uncertainty are to changes in input parameters over the entire input space.
  - Sobol`s method is Monte-Carlo simulation-based GSA, which calculates the total effect indices S_{T_i} of each input parameter X_i. The index S_{T_i} is defined as follows :

$$S_{Ti} = \frac{\mathrm{E}(\mathrm{V}(Y|X_{\sim i}))}{V(Y)} = 1 - \frac{\mathrm{V}\big(\mathrm{E}(Y|X_{\sim i})\big)}{V(Y)},$$

$where\ X_{\sim i}\ is\ all\ input\ parameters\ except\ X_i.$

Data Description

- The Towing Hook experiment data from Hyundai Motor India Engineering (HMIE) is composed of 54 measurements of 12 input and 4 output parameters.
- The four output parameters are measurements of the components for evaluating towing hook performance.
- One of the 12 input parameters is the load value applied to the towing hook, and the other 11 are the design parameters of the elements that constitute the towing hook.

Results

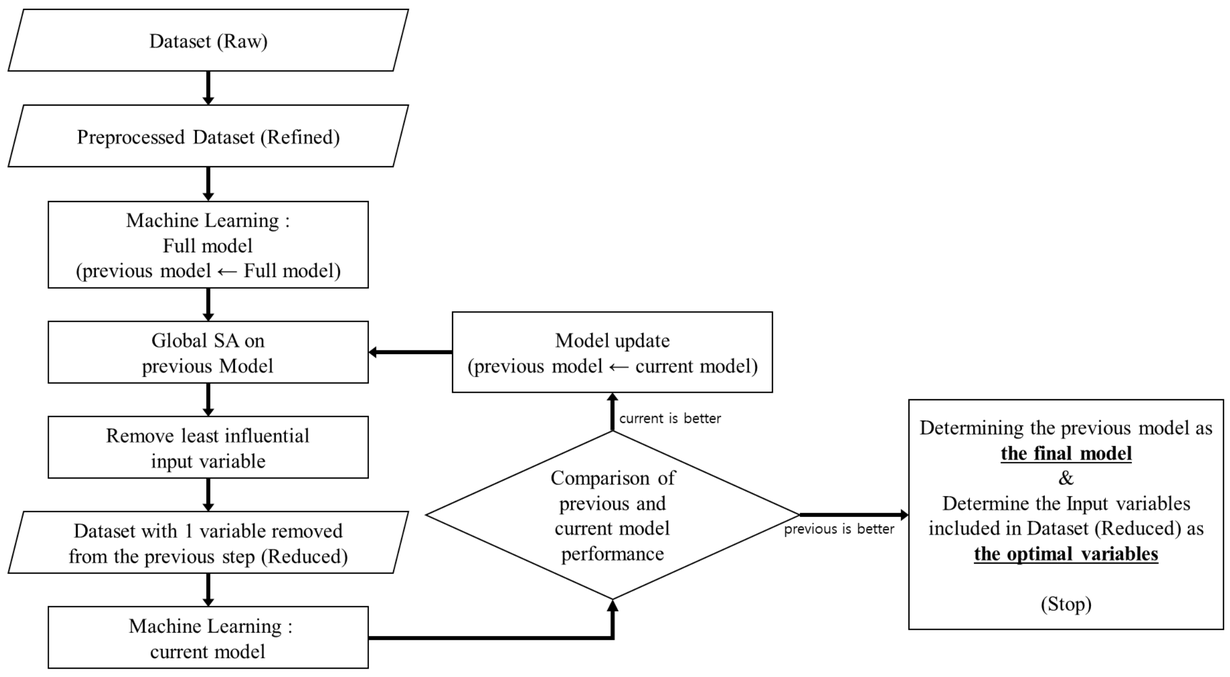

Figure 1. Workflow chart for the research.

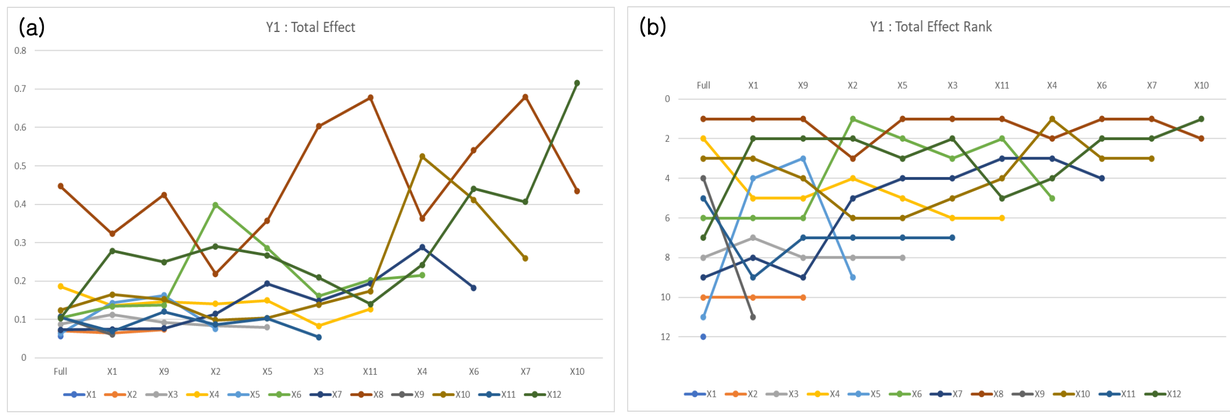

Figure 2. (a) The value and (b) rank of S_{T_i} for output *Y1* at each stage. The horizontal axis lists the order in which the input parameters were removed.

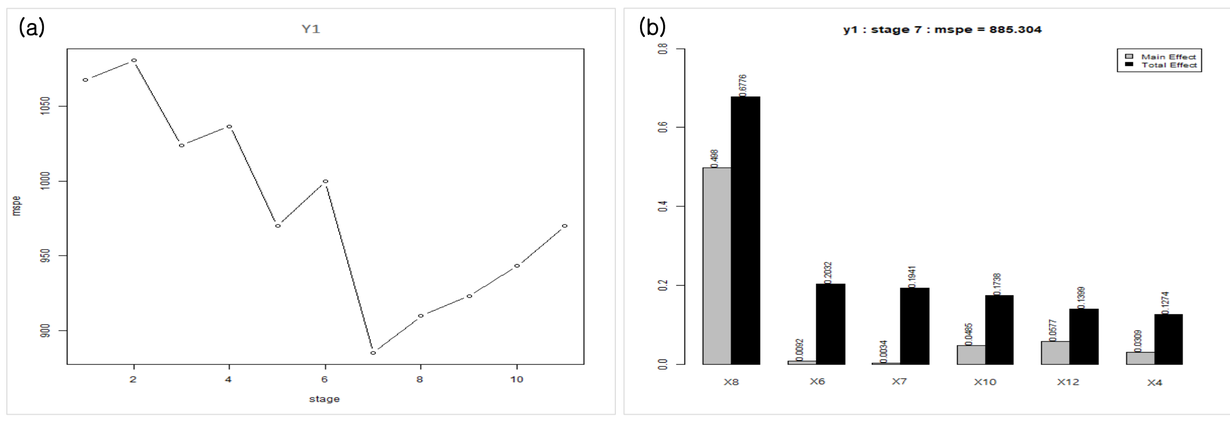

Figure 3. (a) Changes in MSPE at each stage and (b) GSA results for the final model of the output *Y1*.

Table 1. MSPE for each model and the final input parameters for each output parameter

MSPE	*Y1*	*Y2*	*Y3*	*Y4*
Non-descriptive model	1199.294	120.1453	1985.588	2240.499
Full model	1067.577	114.5022	1916.992	2029.686
Final model	885.3043	104.8534	1804.589	1786.312
Final input parameters	*X4 X6 X7 X8 X10 X12*	*X5 X6 X7 X11 X12*	*X1 X3 X5 X6 X8 X9 X10 X11 X12*	*X1 X5 X6 X10 X12*

Conclusion

- For each output, for the sequence of input parameters dropped in the process of building the prediction model, the expert engineer concluded that the analysis was reasonable.
- In the field, the method proposed in this study can be used to construct an appropriate predictive model for model improvement and find parameters that play an important role in the design in a situation where experimental data has already been collected.

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