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Prediction for Motion of Tracked Vehicle Traveling on Soft Soil Using Kriging Metamodel

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To predict the efficiently dynamic responses of a tracked vehicle traveling on soft soil, a metamodel is employed, because computer simulation of a tracked vehicle is quite time-consuming and the responses are highly nonlinear. A rigid-body dynamic model for a tracked vehicle is introduced. For efficient but accurate approximation, the kriging metamodel with a maximum entropy sampling technique is applied. Through the validation using additional sample points, the accuracy of the kriging model is compared with that of a response surface model. It is found that the kriging model predicts dynamic responses better than the response surface model. Further, the kriging model can approximate an accurately nonlinear response of a tracked vehicle traveling on soft soil.

INTRODUCTION

A deep-sea ocean mining collector can consist of 4 parts: pickup device; crusher; transporting equipment to pump the crushed nodules through a flexible hose to the mother station; and tracked vehicle traveling on a semi-liquid layer of deep-sea soil. There is a variety of design requirements for this system, such as a higher collection rate of nodules, lower energy consumption, higher reliability, and lower impact to suboceanic environment. In the concept design stage of this complex and multi-objective system, it is important to create an innovative design through creative thinking, brainstorming, and reasonable decision-making. In the detailed design stage that follows, the need is to compromise the tradeoffs among coupled design variables to obtain the optimal solution. In this stage, it is necessary to employ the concept of simulation-based design, because it is impossible to execute actual experiments in the 5000-m, deep-sea environment.

Recently, multidisciplinary design optimization (MDO) has gained increasing recognition as an efficient methodology that resolves conflicting design requirements in a complex system. For MDO of a mining collector system, various performances should be evaluated by means of computer simulation. We investigate the mobility of an ocean mining collector by using a dynamic tracked vehicle model that is assumed to have a rigid chassis and rigid tracks. In dynamic analysis, the traveling performance of a tracked vehicle is sensitively influenced by the characteristics of the cohesive soil in deep-sea ground. The properties of cohesive soil are modeled in terms of pressure-sinkage relationship and shear displacement–stress relationship. Thus, the spatial distribution of shear stress around the contact surface should be calculated exactly, as the trafficability of the vehicle is directly related to shear stress. Especially, shear stress of cohesive soil is nonlinear to shear displacement. As a result, the nonlinearity of responses and the complexity of the system cause time-consuming analysis of the tracked vehicle. However, the considerable computational cost of dynamic analysis at one time can be a serious obstacle in MOD, because many dynamic analyses are generally executed during the optimization process. It is then necessary to reduce the number of actual complex dynamic analyses during the simulation-based design process.

To reduce the number of actual simulations, metamodeling techniques approximating a complicated and computationally expensive simulation model have gained growing recognition in recent years. The basic concept of metamodeling technique is to provide an approximate model of a complex and time-consuming model through a moderate number of computer experiments, and then to use the approximate model for design or optimization. The primary benefit of the metamodel is to render large-scale optimization or MDO computationally achievable. In addition, the metamodel provides the designer with approximate design information for a complicated and expensive system through computationally cheap evaluations. That is, the metamodel can be employed as a simulator to improve and verify the design.

A variety of metamodels has been developed, such as the response surface model (Myers and Montgomery, 1995), radial basis functions (Dyn et al., 1986), the kriging model (Sacks et al., 1989; Ryu et al., 2002), multivariate adaptive regression splines (Friedman, 1991), etc. Among these metamodels, the response surface model and kriging model have been used widely in the approximation of various engineering problems. Conceptually, the response surface model is the regression model expressed as a linear combination of polynomials, in which unknown coefficients are estimated by minimizing the least square of errors. Kriging, the so-called design and analysis of computer experiment (DACE) model, is the interpolation model where the prediction coincides with the simulation response at sampled points exactly. Especially, the kriging model has found much success in the approximation of highly nonlinear engineering systems.

In the design and analysis of a computer experiment, replication is generally meaningless because the response of computer simulation is deterministic, i.e., rerunning the simulation code with the same input always gives identical output. Hence sample points should be evenly distributed over the entire design space in order

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