International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 10 (2015) pp. 26037-26047

http://www.ripublication.com

Surrogate Modeling of Quadruple Tank System

V. Mamtha, S. Rakesh Kumar
Department of Electronics and Instrumentation Engineering
SASTRA University, thanjavur-613401, India
Ph: 9488915157, mail:mamthasrimail@gmail.com

Abstract

In the world of engineering design surrogate modeling method is highly facilitating tool. Surrogate Models are the best cheap alternatives for the real time systems of computationally expensive simulations. In this document the main concept is to model a quadruple tank system using surrogate modeling technique. The main advantage of this approach is to approximate the real time system using the adaptive sampling approach. Generally the surrogate model is known as the model which replaces a model or the real-time system. Here surrogate model is taken by the combination of data driven approach and adaptive sampling technique. The Artificial Neural Network (ANN) modeling technique is used to model a quadruple tank system which is the simple method to train the data's as a model rather than other methods . Procedures to construct surrogate model and applicability of Artificial Neural Network (ANN) model and validation of models using RMSE were discussed.

Key words: surrogate model, quadruple tank, RMSE, data driven approach, ANN.

Introduction

The development in computational simulations using the Surrogate Modeling technique has proven to reduce the computational expenses and process duration of the model. Abundant methods are existing to approximate and model a real time system. The modeling of non-linear real time system is difficult because of its non-linearity, large dataset and high processing duration. Using the Surrogate Modeling technique reducing the difficulties of modeling the non-liner system is possible.

The aim is to provide the parameterized (scalable) model of quadruple tank system. Surrogate modeling technique is based on data-driven approach, this approach is not make any assumptions analytically for the model which has to be reduced. Based on the input data set only the model got trained . The model is known as a 'black box' which intakes the input samples and provides the output samples. Based

on the initial set of samples the response surface curve of ANN model is plotted. Adaptive sampling technique is proposed to achieve accuracy of the model. While the accuracy of the model is less by adding adaptive samples in the model is help full to reached the expected model accuracy.

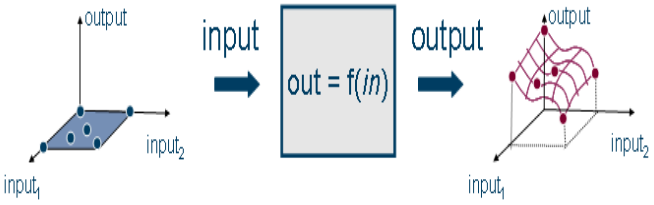

Figure 1.1: General surrogate modeling approach

Surrogate Modelling

The surrogate model is proposed model in this paper which replaces another model to achieve the fast and accurate response. The model which mimics the input output behavior of the complex This models can predict the output of the system (which is not in the given data set while training). In this paper developing the relationship between the input and output in the ANN (Artificial Neural Network)model using the Delaunay triangulation method. There are many approximation modeling methods are there. Those models are replacements of real time systems with their own relative merits. These methods are (Example: kriging models, artificial neural networks (ANN), splines, Support Vector Machines (SVM)) known as approximation modeling methods.

Construction of surrogate modeling containing several steps the flow chart given below which gives detailed explanation about the construction of the surrogate model.

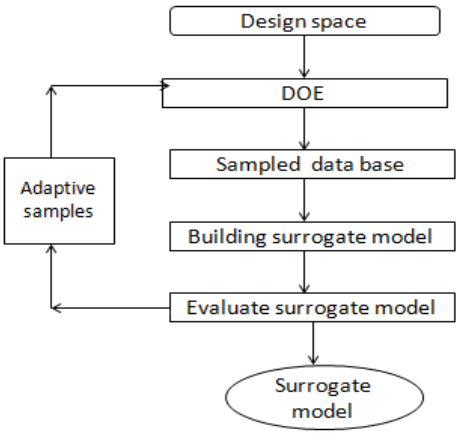

Figure 2.1: Flow chart of surrogate model

Procedure of Surrogate Modelling

Assuming the design space of the real time system which contain maxima and minima value of the system dataset. Using Design Of Experiment (DOE) method get the initial sample data of the real time system. From the Design Of Experiment (DOE) get the sample or initial data set. Build the surrogate model using any data driven modeling method in this paper the surrogate model was build using ANN artificial neural network . Evaluate the model for the RRMS, RMS, ELAPSETIME values the model accuracy is less than expected accuracy add adaptive samples and repeat the process from DOE till get the expected accuracy. After reach the expected accuracy get the surrogate model.

Quadruple Tank System

The quadruple tank process system which contains four tanks tank1 and tank3 are the upper level tanks and tank2 and tank4 are the lower level tanks. The upper level tanks flows down to the lower level tanks which parallel with each other. Pump1 supply the liquid flow for tank1 and tank4,and pump 2 supply the liquid flow of tank 2 and tank3.

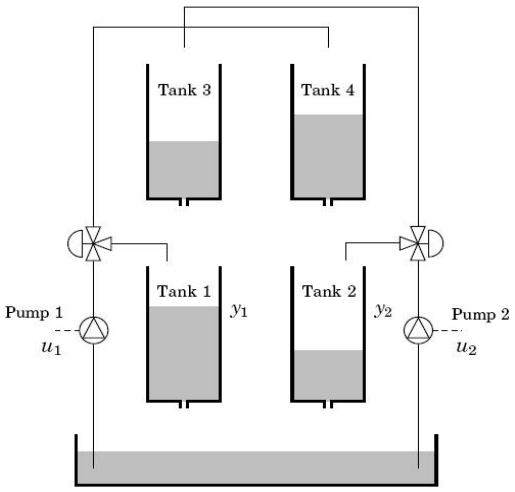

Figure 3.1: Quadruple tank process

The input control signals v1, v2 are control signals of the pumps, and y1, y2 are the signals from the water level sensors which consider as the output signal of the quadruple tank system. The mathematical model of quadruple tank process is given

$$\frac{dh_1}{dt} = -\frac{a_1}{A_1}\sqrt{2g(h_1 - h_2)} + \frac{(1-\gamma_a)}{A1}V_1 \qquad (1)$$

$$\frac{dh_2}{dt} = -\frac{a_2}{A_2}\sqrt{2gh_2} + \frac{a_1}{A_2}\sqrt{2g(h_1 - h_2)} + \frac{\gamma_b}{A_2}V_2 \quad (2)$$

$$\frac{dh_3}{dt} = -\frac{a_3}{A_3}\sqrt{2g(h_3 - h_4)} + \frac{(1-\gamma_b)}{A_2}V_2 \quad (3)$$

$$\frac{dh_4}{dt} = -\frac{a_4}{A_4}\sqrt{2gh_4} + \frac{a_3}{A_4}\sqrt{2g(h_3 - h_4)} + \frac{\gamma_a}{A_4}V_2 \quad (4)$$

In the mathematical model where h1, h2, h3, h4 are the height of tank1, tank2, tank3, tank4 respectively.a1, a2, a3, a4 are the area of the over flow pipes of tank1, tank2, tank3, tank4 respectively. A1, A2, A3, A4 are the area of tank1, tank2, tank3, tank4 respectively. ‘g’ denotes that gravity. r is valve positions. This model formed based on Bernoulli’s theorem.

Surrogate Model of Quadruple Tank System

Using the surrogate modeling technique the quadruple tank is modeled which is discussed here. The initial set of data is gain from the real time process which is shown in thefigure4.1

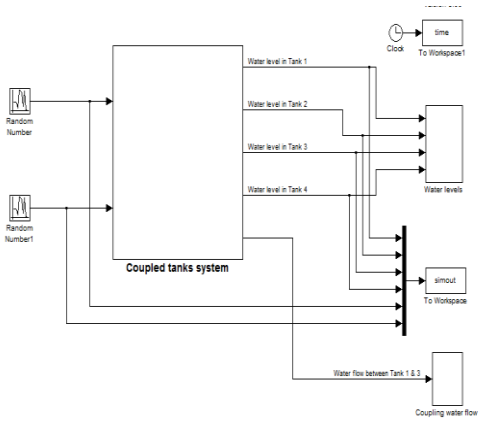

Figure 4.1: Real-time quadruple tank system

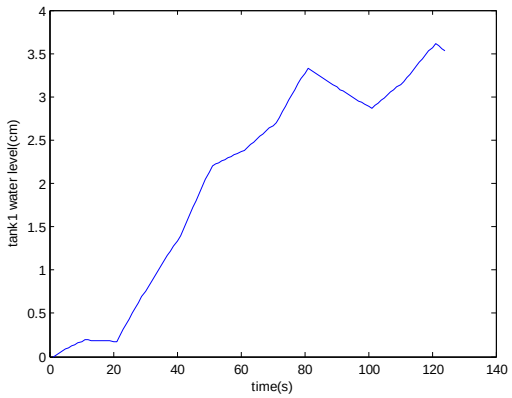

Figure 4.2: Water level Tank 1 of real time system

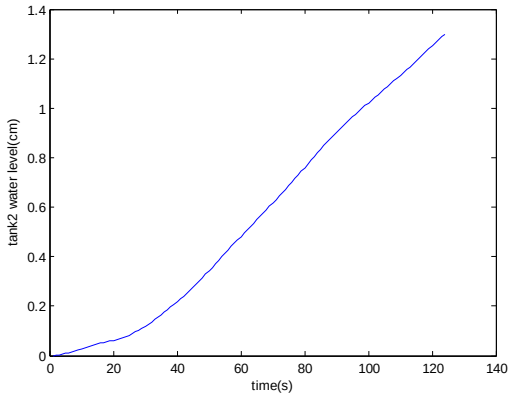

Figure 4.3: Water level Tank 2 of real time system

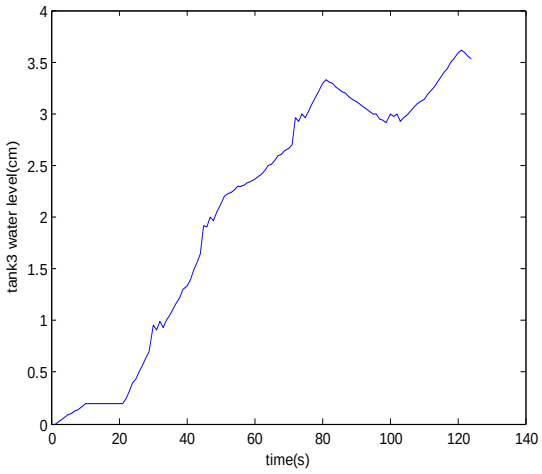

Figure 4.4: Water level Tank 3 of real time system

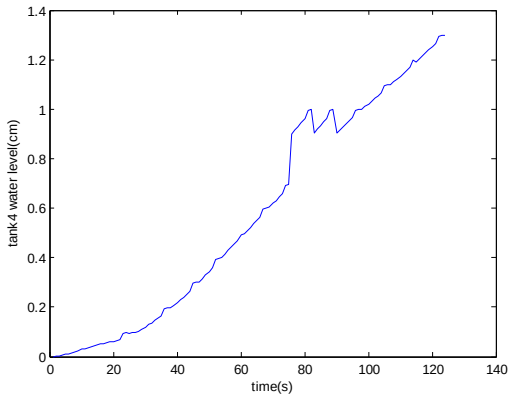

Figure 4.5: Water level Tank 4 of real time system

From the real time system the input control signals and output signals are measured. This measured value of real-time system is known as dataset. Using the dataset from the real time system as initial sample which is feed to the surrogate model . The ANN is trained from the initial set of data .the inputs of ANN (Artificial neural Network) is input signal of pump (v1,v2), water level of the tank (t1,t2,t3,t4). Using data driven approach and the Delaunay triangulation the ANN(Artificial Neural Network) response surface is plotted. the data driven method is a method which frequently using in the engineering modeling field which consider or create the system using the initial set of data's the approach which also predict the system using initial data set.

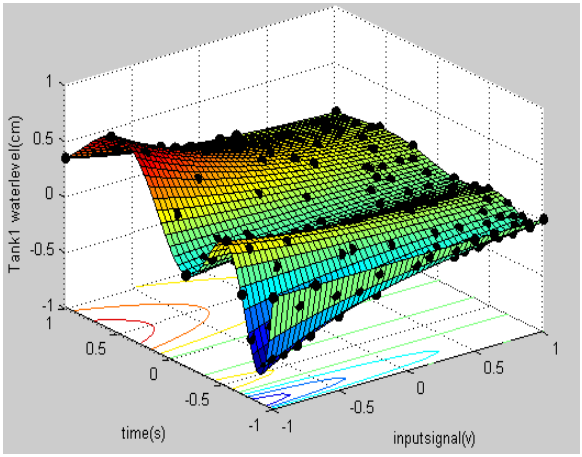

Figure 4.6: ANN model of quadruple tank system for tank1

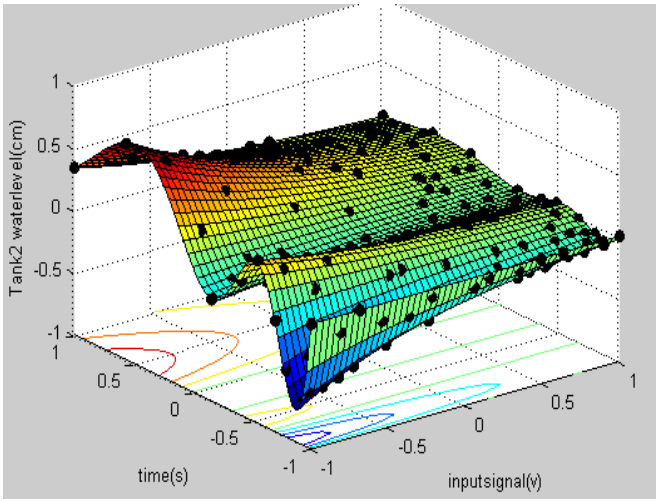

Figure 4.7: ANN model of quadruple tank system for tank2

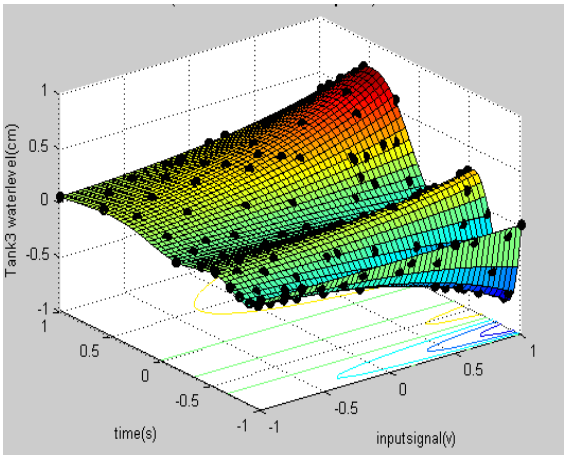

Figure 4.8: ANN model of quadruple tank system for tank3

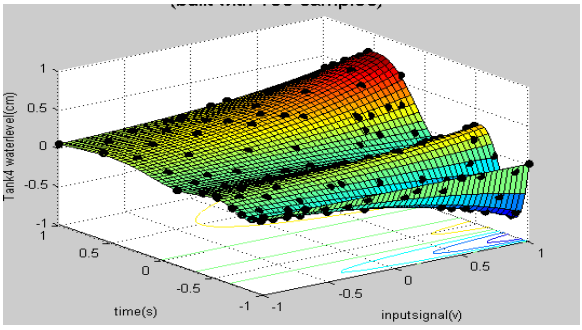

Figure 4.9: ANN model of quadruple tank system for tank4

Validation

Validation is the process which check for accuracy of the model and calculating the RMSE value.when the RMSE(Root Mean Square Error) value is less then 0.5 the model is known as preferable model .in this paper the approched modeling system is getting less then 0.5 RMSE value after adding 6000 adaptive smples. Using adaptive sampling technique reach more accuracy and less RMSE value.adaptive sampling technique make the model simple and less elapse time .

The RMSE(root mean square error) is defined by follwing mathematical equation.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(p_i - a_i)^2}{n}}$$

Pi-Target value
ai- actual value
n- samples

Table 5.1 RMSE values

Tank	**RSME**
Tank1	0.2376
Tank2	0.3631
Tank3	0.2772
Tank4	0.2931

Result & Discussions

In this section, simulation results demonstrate and validate Surrogate Models created with same set of inputs and different outputs for quadruple tank process are discussed.

The real time system output after prediction and the output of surrogate model where compared and validated for accuracy.

The RSME(root mean square error) should be less than 0.5 for the model after adding 6000 adaptive samples the accuracy is achieved then the model is behaves like the real time system and which mimic input output behavior of the real-time system.

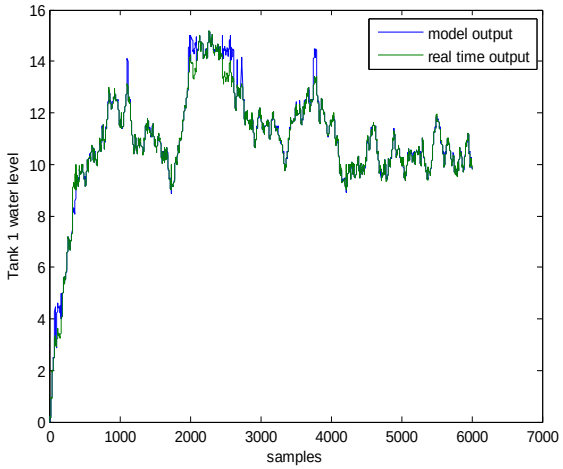

Figure 6.1: Comparison of real time system and surrogate model system tank1

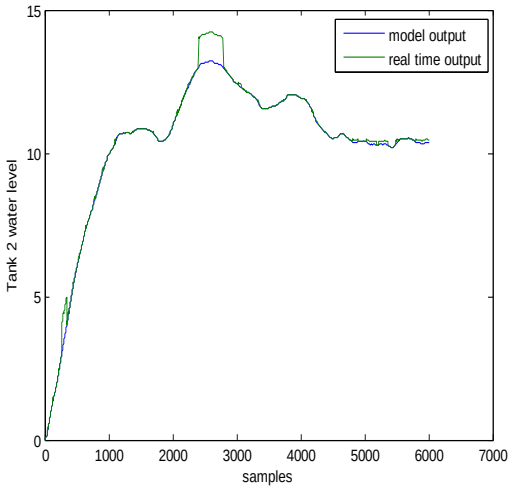

Figure 6.2: Comparison of real time system and surrogate model system tank2

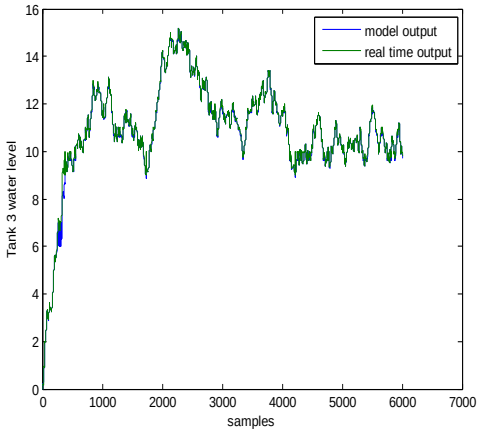

Figure 6.3: Comparison of real time system and surrogate model system tank3

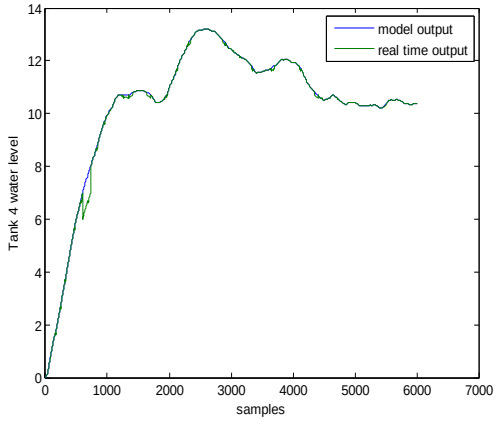

Figure 6.4: Comparison of real time system and surrogate model system tank4

Conclusion

Development and validation of surrogate models were discussed in this paper. Designing of non linear process is challenging task. Surrogate modeling technique providing the accurate model of the real time system. To achieve accurate model the data driven method and adaptive sampling methods are fallowed. Surrogate model of large non-linear system is simple and cost effective, elapsed time is very less.

Reference

[1] Chen wang, Qingyunduan, Wei gong, Aizhong ye, Zhenhua di, Chiyuanmiao, “An evaluation of adaptive surrogate modelling based

optimization with two benchmark problems", Environmental Modelling & Software ISSN1364-8152/©2014 july 2014.

[2] Designdirkgorissen Ivo couckuyt, PietDemeester, Tomdhaene"A surrogate modelling and adaptive sampling toolbox for computer based design" Journal of Machine Learning Research 11 (2010) 2051-2055; published 7/10.

[3] Zhiguangqian, Carolyn conner ,"Building surrogate models based on detailed and approximate simulations," TX 7875668 / Vol. 128, JULY 2009 Copyright © 2009 by ASME Transactions of the ASME.

[4] Karl Henrik Johansson "The Quadruple-Tank Process: A Multivariable Laboratory Process with an Adjustable Zero." IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, VOL. 8, NO. 3, MAY 2000.

[5] Prof. D. Angeline Vijula, Anu K, Honey Mol P, Poorna Priya s "Mathematical Modelling of Quadruple Tank System" International Journal of Emerging Technology and Advanced Engineering ISSN 2250-2459, Volume 3, Issue 12, December 2013.

[6] D. Allaire and K. Willcox Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 "Surrogate Modeling for Uncertainty Assessment with Application to Aviation Environmental System Models" AIAA JOURNAL Vol. 48, No. 8, August 2010

[7] Felipe A. C. Viana Raphael T. Haftka Valder Steffen Jr. "Multiple surrogates: how cross-validation errors can help us to obtain the best predictor" Struct Multidisc Optim (2009) 39:439–457 DOI 10.1007/s00158-008-0338-0 © Springer-Verlag 2008