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Application of a real-time predictive maintenance system to a production machine system

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Abstract

This paper develops earlier work that established the possibility of the classification of machine system parameters on the basis of motion current signature, using a neural network approach. A neural network requires a large amount of training data, which is impractical to generate using a production machine for real-time predictive maintenance system. Hence, a simulation model, which mapped the system parameters to the motion current signature, was developed. The accuracy of the system, to predict the changes in the value of the machine system parameter, is a direct function of the validity of the simulated data. Thus, the objective validation of the simulation model is important to ascertain that the simulation model is accurate with regards to its purpose.

In this paper, the simulation model is validated against an on-line production machine. Various approaches to validate the simulation model are applied and a simulation model is developed.

Keywords: Neural network; Motion current signature; Validation; Simulation model; TuneLearn; BJEST; Sensitivity analysis; Graphical comparison; Visual comparison

1. Introduction

Servo motors are ubiquitous amongst machine applications. The need for efficiency and maximum production time creates a requirement for high reliability supported by an effective maintenance system for servo motors. Recent studies have demonstrated that predictive maintenance can ensure high reliability and performance [1–7].

Earlier work has introduced an effective, real-time, predictive maintenance system based on the motion current signature using a neural network approach [8]. The aim of the system is to localize and detect abnormal electrical conditions in order to predict mechanical abnormalities.

A fundamental requirement for the successful application of a neural network is the availability of relevant, information-rich training data. While an ideal solution would be to utilize training data from a real production system, it is impractical to scan the entire range of machine operations [8].

Mathematical simulation models are increasingly being used in problem solving and in decision making [9]. Thus, the use of a simulation model for generating the training data, covering harder to replicate machine conditions, like current limit overrun, was motivated [8]. A simulation model, TuneLearn,[1] of a closed loop form based on a PID controller was developed and shown to be capable of mapping the motion current signature to the system parameters [8].

The developers and the users of the models, the decision makers using information derived from the results of the models, and the people affected by decisions based on the simulation models are all rightly concerned with whether

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Nomenclature

BJEST	Bansal–Jones estimation	μ_y	mean of simulated output
SATF	segment-wise average torque feedback	T	total torque feedback
x	time series of real output	Acc	instantaneous acceleration
y	time series of simulated output	J	system inertia
β_0	intercept of the line	Sign	motoring or regenerating condition of the motor
β_1	slope of the line	F	friction torque
μ_x	mean of real output	G_t	gravitation torque

a model and its results are 'correct' and 'useful' [9–11]. This concern is addressed through model validation. Model validation can be defined as "determining whether the simulation model is an acceptable representation of the real system—given the purpose of the simulation model" [10,11]. This motivates the validation of the TuneLearn against a real on-line production machine and a test rig.

A model is required to be developed for a specific purpose (or application) and its validity has to be determined with respect to that purpose [9]. A model is considered valid for a set of experimental conditions if its accuracy is within its acceptable range, which is the amount of accuracy required for the model's intended purpose. The intended purpose of the real-time predictive maintenance system is to determine changes in the value of the machine system parameters, like inertia, frictional torque and gravitational torque. On the other hand, the intended purpose of the TuneLearn is to simulate the macro dynamics of the torque feedback (or the motion current signature) using the system parameters and the motion profile as the input. The macro dynamics of the torque feedback include instantaneous values of the direction and the magnitude of the torque feedback, averaged over a velocity segment.

The accuracy of the real-time predictive maintenance system can be defined as $\pm 1\%$ of the change in the vale of the predicted machine system parameter, i.e. the accuracy of two significant figure.

It is often too costly and time consuming to determine that a model is absolutely valid over the complete domain of its intended applicability [9]. Instead, tests and evaluations can be conducted until sufficient confidence, which is when the accuracy of the model is equal or higher than the intended accuracy, is obtained that a model can be considered valid for its intended application [12,13,21].

The remainder of this paper is organized as follows: Section 2 discusses the organization of the validation process adopted in this paper to assess the model validity; Sections 3 and 4 provide a brief description of the production machine and the test rig, respectively; Section 5 defines the procedure for collecting the motion current signature from the production machine; Section 6 describes the BJEST (Bansal–Jones Estimation) algorithm, which is a single order algorithm to calculate the system parameters, needed for modelling the production machine and the test rig, using the torque feedback; Section 7 provides the results of the application of the BJEST; Section 8 details the application of the validation process; and Section 9 gives the conclusions.

2. Validation process

The use of statistics has been shown to be an effective technique for performing model validation [10,14,16,18,19]. It has been argued that, because simulation means experimentation, and any experimentation calls for statistical analysis, the use of statistical techniques for simulation validation should be preferred [10]. The statistical techniques have the advantage of yielding reproducible, objective, quantitative data about the quality of a given simulation model [20].

The TuneLearn validation is based on the statistical and intuitive techniques [10]. The validation is done in three steps:

(1) Sensitivity analysis—parameter variability;
(2) Graphical comparison;
(3) Regression analysis;

The Sections 2.1–2.3 explain the three steps in detail.

2.1. Sensitivity analysis

This technique consists of changing the values of the input and the internal parameters of a model to determine the effect upon the model's behavior and its output. The same relationship should occur in the model as in the real system [15,17,19,11]. In principle, sensitivity analysis is based on a simple idea: change the model inputs and observe the behavior.

An important decision in sensitivity analysis is the selection of the model input parameters to be varied and the combination in which the parameters will be varied. The selection of input parameters is based upon the effect of the parameter on the model output, and the intended application of the model.

An important term in the sensitivity analysis of TuneLearn is the segment-wise average torque feedback (SATF). The motion profile command of the system comprises of