International Journal of Industrial Ergonomics 67 (2018) 283–295

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Artificial intelligence models for predicting the performance of hydro-pneumatic suspension struts in large capacity dump trucks

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ARTICLE INFO

Keywords:
Artificial intelligence
Artificial neural network
HyFIS
Mamdani fuzzy logic
Suspension system
HISLO
Dump truck
Whole body vibrations

ABSTRACT

Large dump trucks are being matched with large shovels to achieve bulk economic production in surface mining operations. This process results in high impact shovel loading operations (HISLO) and exposes operators to severe levels of whole-body vibrations (WBV). The performance of the hydro-pneumatic suspension struts, responsible for vibration attenuation in large dump trucks, decreases as a truck age. There is a need for a system for monitoring and predicting the performance of the suspension struts in real time. Artificial intelligence (AI) has been applied for modeling and predicting the suspension system performance for light/smaller vehicles. However, no work has been done to implement AI for modeling and predicting the performance of hydro-pneumatic struts in large dump trucks. This paper is a pioneering effort towards developing AI models for solving this problem. These AI models would incorporate the Artificial Neural Networks (ANN), Mamdani Fuzzy Logic (MFL) and a hybrid system, the Hybrid Neural Fuzzy Interference System (HyFIS), for achieving this goal. Experiments were conducted using a 3D virtual simulator for the CAT 793D in MSC.ADMAS. RMS accelerations in the vertical and horizontal directions at the operator seat were recorded as the two main outputs for the suspension system performance. Eighty percent (80%) of the total experimental data was used in training and developing the models and the remaining 20% for testing and validating the developed models. With an R^2 and RMSE of 0.98168505 and 0.00852251 for the training phase, respectively, and 0.9660429 and 0.0195620 for the testing phase, HyFIS model showed the best accuracy for predicting the hydro-pneumatic suspension struts performance for dump trucks. This is the first time that AI models have been developed for dump truck suspension system performance prediction. With the implementation of these models in the dump truck, maintenance personnel can monitor the performance of the suspension system in real-time and schedule proper maintenance and/or replacement. Implementation of such a system will improve the workplace safety, operator's health and the overall system efficiency.

1. Introduction

Large capacity shovels and dump trucks are being employed in surface mining operations across the world for achieving bulk economic production. As large-capacity shovel loads material weighing 100 tons or more into the dump truck under gravity, the dynamic impact force is generated which results in high frequency shockwaves. These shockwaves travel through the truck body and chassis into the operator's cabin and expose operator to severe levels of whole-body vibrations (WBV). The International Standards Organization (ISO) has listed the recommended safe limits in sections 1, 2, 4 and 5 of ISO 2631 (1997, 2003, 2001 and 2004). Exposure to the WBV levels beyond those limits can result in severe long-term back, shoulders, arms and neck disability and disorders.

Ali and Frimpong (2018) have modeled the dynamic impact force form high impact shovel loading operations (HISLO). The methodology for reducing the impact force by optimizing the dumping process has been provided by Ali and Frimpong (2017). In addition to the optimization of dumping process, there is a need to improve the vibration attenuation system in the dump truck. Hydro-pneumatic suspension struts are most commonly used in large dump trucks as the vibration attenuation system. With aging, the suspension system deteriorates and loses its capability to effectively attenuate the impact of vibrations produced by the dumping process under gravity. This is due to the contamination of hydraulic oil, mixing of the oil and nitrogen or rupturing of the gas accumulator diaphragm. The effectiveness of any suspension system is evaluated by determining the output vibration levels. In case of the dump truck, it is important to determine the vibration levels at the operator's seat for evaluating the effectiveness of the hydro-pneumatic suspension struts as the truck ages.

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https://doi.org/10.1016/j.ergon.2018.06.005
Received 4 April 2018; Received in revised form 7 May 2018; Accepted 19 June 2018
0169-8141/

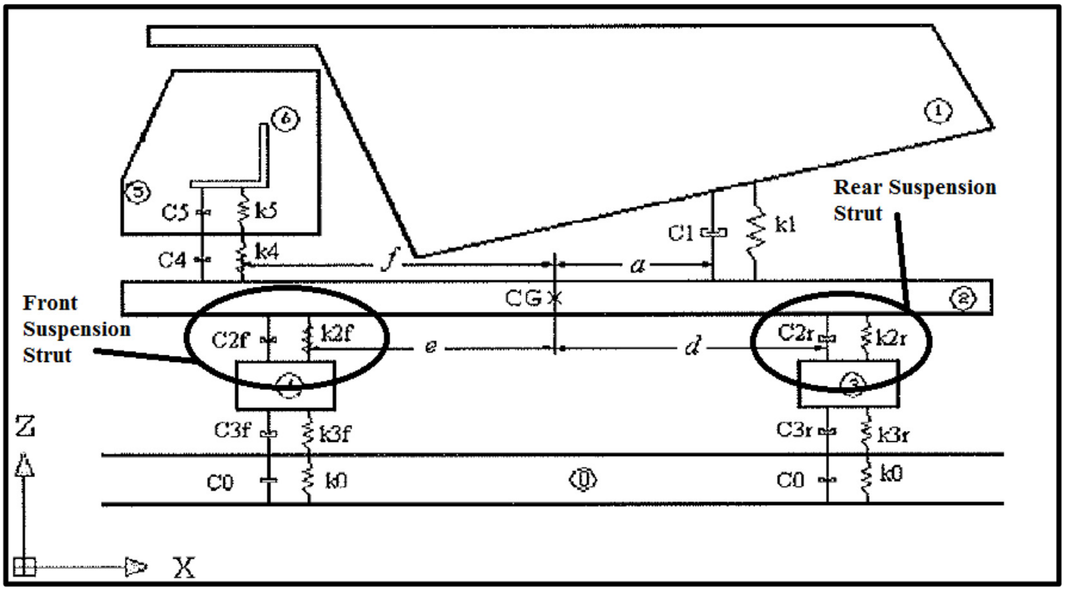

Fig. 1. Free Body Diagram of Dump Truck showing the Rear and Front Hydro-Pneumatic Suspension Struts (Aouad and Frimpong, 2013).

AI models can be used for suspension system modeling and performance prediction. Dindarloo (2016) studied the effect of aging on dump truck suspension system and provided an offline simulation system for determining the performance of the suspension system. However, the offline simulation setup requires integration of multiple software platforms, running multiple experiments for model check and an in-depth technical expertise related to multi body dynamics for developing and running the simulation. Moreover, it has to be updated manually. AI models, on the other hand, allows construction of an intelligent system that predicts the outcome (suspension performance) with high precision without a need for multi body dynamics modeling. The AI system is also self-learning and doesn't require any human involvement. Therefore, with an exceptional computational accuracy of AI models, the current methodology is not only efficient but also economic and faster. The proposed AI models can be implemented in the truck controller system for continuous performance evaluation of the suspension system.

Guarneri et al. (2008) used recurrent neural networks (RNNs), which are derived from the multi-layer artificial neural network for tire/suspension dynamic modeling. The model was trained on an experimental data and then used for predicting the behavior of elastic brushing and tire dynamics. Yanting et al. (2008) proposed a method using ANN with adaptive control methodology for setting up an engine-vehicle suspension control system. They showed that the system performed better than the traditional control systems. Bhanot (2017) used feed-forward ANN to develop a velocity sensitive damper model for a vehicle suspension system that achieves a better control and performance. Heidari and Homaei (2013) used back-propagation ANN to determine the optimum parameters for designing a PID controller for a vehicle suspension system. Yıldırım and Eski (2009) used ANN to analyze and predict the automotive suspension system performance. Muderrisoğlu et al. (2016) proposed a PID controller for a vehicle suspension system based on ANN to enhance its performance. Ranjbar-sahraie et al. (2011) proposed a controller for a car suspension system based on Mamdani Fuzzy Logic (MFL) model. Pekgökgöz et al. (2010) proposed a controller using Mamdani Fuzzy Logic (MFL) model and genetic algorithm for controlling the active suspension systems. Gao et al. (2004) used ANN to model and predict the performance of a vehicle strut. The model was trained using the experimental results from road profile simulations. Yildirim (2004) used the feedforward ANN to model a bus suspension system, for enhancing the performance of its suspension system.

Researchers have mainly used ANN and Mamdani Fuzzy Logic models for automobile suspension system modeling and performance prediction. No work has been carried out for modeling and predicting the performance of dump truck hydro-pneumatic suspension struts. No researcher has previously used the hybrid neural technique for suspension system performance modeling. This is the first attempt to apply these AI and machine learning (ML) models namely Artificial Neural Networks (ANN), Mamdani Fuzzy Logic (MFL) and Hybrid Neural Fuzzy Interference System (HyFIS) for modeling and predicting the performance of hydro-pneumatic suspension struts in large dump trucks for vibration attenuation.

1.1. Scope and methodology

The models will be developed and optimized primarily for CAT 793D. A virtual simulator will be developed for CAT 793D in MSC. ADAMS by utilizing the model constructed by Aouad and Frimpong (2013). Several virtual experiments will be conducted to gather performance data for the hydro-pneumatic suspension struts of the CAT 793D. The experimental data will then be used to develop and train the AI and machine learning (ML) models. The AI/ML models will then be validated and tested phase for evaluating their performance in predicting the condition and performance of the suspension system.

2. HISLO phenomenon in truck loading and 3D virtual simulation setup

There are two pairs of rear and front hydro-pneumatic struts (Fig. 1) in the CAT 793D truck for attenuating the shockwaves from the large dynamic impact force. During loading, the primary job of these struts is to decrease an operator's exposure to high WBV levels and thus, providing comfort to the operator. Thus, the performance of these hydro-pneumatic struts can be characterized and evaluated based on the WBV levels at the operator's seat.

Spring and damper are the two main elements which govern the effectiveness of the suspension system. As the truck ages, these elements lose their functioning capabilities. These two elements are characterized by the spring stiffness and damping coefficient. The 3D virtual simulator, with 38 DOF, for the CAT 793D truck, based on the model developed by Aouad and Frimpong (2013), was used to conduct detailed virtual experiments as shown in Fig. 2. The MSC.ADAMS environment was used to simulate the model for HISLO conditions.