Energy 93 (2015) 1704–1710

Contents lists available at ScienceDirect

Energy

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

Appraisal of artificial neural network-genetic algorithm based model for prediction of the power provided by the agricultural tractors

Hamid Taghavifar [a, *], Aref Mardani [a], Ashkan Haji Hosseinloo [b]

[a] Department of Mechanical Engineering of Biosystems, Urmia University, Urmia, Iran
[b] Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

ARTICLE INFO

Article history:
Received 20 April 2015
Received in revised form
8 September 2015
Accepted 17 October 2015
Available online 19 November 2015

Keywords:
Artificial intelligence
Power
Soil bin
Tractor
Off-road vehicles

ABSTRACT

The knowledge of the available power provided by the driving wheel of agricultural tractors is required to gain a correct insight into the energy management of agricultural tractors. The design of the tractors is pivotal on the maximization of the traction efficiency and simultaneous minimization of energy dissipation. This paper spearheads the synthesis of the power provided by the agricultural tractors as affected by wheel load, slip and speed by use of the potential of a soil bin facility and a single-wheel test rig. The hybridized artificial neural network-genetic algorithm method was adopted to model the provided power of the driving wheel under the effect of the aforementioned tire parameters. The common drawback of the back-propagation algorithm known as the low speed of convergence and the possibility of being trapped in a local minimum was solved by the use of genetic algorithm. The mean square error equal to 0.02242 was obtained as the most optimal artificial neural network-genetic algorithm configuration using Levenberg–Marquardt training algorithm. Therefore, a 3-9-1 feed-forward with back propagation learning algorithm was selected as the modeling structure. The computed coefficient of determination for the training and test phases of the best artificial neural network-genetic algorithm model was obtained at 0.9696 and 0.9672, respectively. The present study spearheads the required power estimation for the driving wheels of off-road vehicles while the experimental test conduction in a controlled soil bin facility using single-wheel tester and adoption of soft computing tools are of the highlights and added values of the paper.

1. Introduction

Agricultural tractors are responsible for a diversity of mechanized tasks in the farmlands from cradle to grave (i.e. from tillage operation to the post-cultivation process). With the ever-increasing tendency towards the application of these instrumental vehicles to increase the crop yield, the concentration has been on the maximization of the performance of tractors. Tractor performance is closely associated with the traction force provided by the driving wheels at the soil-tire interface [1]. While a broad spectrum of energy science is associated with the wheeled vehicles, the energy waste of off-road vehicles is among the mainstream domains of energy management. Wheel is playing an important role in agricultural and off-road vehicles since it is always in contact with farm, nearly all of moment/forces affecting the mobility of vehicle are applied to it, and also it has a very noticeable effect on machine dynamics [2]. Wheel also plays a very substantial role in determination of the performance and efficiency of the vehicle as wheel is subjected to all of the forces and torques exerting to the vehicle [3]. A satisfactory understanding of the power provided by an off-road vehicle is pivotal on the wheel–terrain interaction phenomenon. A primary area of interest has been the subject of efficient power delivery to the wheels from the engine and low-dissipated energy at soil-wheel interface. This topic has stimulated lots of researches to synthesize the net traction as a major index of vehicle performance from the energetic point of view. The scenarios that deal with the efficient power delivery to the implements pulled/pushed by the tractors are considered to be affected by both of soil and wheel physical-mechanical characteristics. In this regard, the identification of soil-wheel contact patch leads to a qualitative and quantitative measure of the tractive parameters. The unsatisfactory

* Corresponding author. Dept. of Mechanical Engineering in Biosystems, Urmia University, P.O. Box 165, Urmia, Iran. Tel.: +98 921 438 2608; fax: +98 443 277 9559.
E-mail addresses: ha.taghavifar@urmia.ac.ir, hamid.taghavifar@gmail.com (H. Taghavifar).

http://dx.doi.org/10.1016/j.energy.2015.10.066
0360-5442/

Nomenclature

ANFIS	adaptive neuro-fuzzy inference system
ANOVA	analysis of variance
ANN	artificial neural network
DEA	data envelopment analysis
GA	genetic algorithm
logsig	log-sigmoid transfer function
MSE	mean square error
R^2	coefficient of determination
RSM	response surface methodology
trainlm	Levenberg–Marquardt back propagation
X_n	normalized input variable
$X_{r,min}$	minimum of input variable
$X_{r,max}$	maximum of input variable
X_h	maximum normalized data
X_l	minimum normalized data
X_r	raw input variable

quality of wheel–terrain interaction brings about 20–55% of tractor power losses [4]. This is a significant amount of power loss which validates the requirement of the present study to be dedicated to the power loss synthesis of off-road driving wheel.

A single-wheel tire testing facility was used to assess the potentiality of the commonly used traction models for tires used in Indian soil conditions and consequently, the coefficients of traction prediction equations were renewed and modified [5]. A tire traction testing facility was also manufactured to spearhead a fundamental research on traction mechanics with high-lug agricultural tires and the developed facility was satisfactorily analyzed to obtain motion resistance data and net traction ratios for high-lug agricultural tire at the suggested inflation pressure on the prototype soil texture [6]. The effect of soil conditions on tractive performance of wheeled and tracked vehicles was investigated methodically while the obtained results showed that soil properties and parameters as well as soil moisture content and density significantly affects the tractive performance of an off-road vehicle [7]. A comprehensive method for prediction of off-road driven wheel performance was carried out, assuming a parabolic wheel–soil contact surface while the load transfer effect was measured the proposed model for the prediction of the traction performance of a 4WD vehicle was appraised [8]. Field experiments on off-road vehicle traction and wheel–soil interactions were performed on different soil textures with adoption of a heavy 14 T, 6 × 6 military truck equipped with 14.00–20 10 PR tires inflated at about 390 kPa. The results showed that reduced inflation pressure had positive effects on traction and increased stress under wheels and that the increasing wheel load resulted in increasing the traction force [9].

Literature survey revealed the following results for the consideration of energy assessments of wheeled vehicles. The prediction of energy efficiency indices of driven wheels (i.e. traction coefficient and tractive power efficiency) as affected by wheel load, slip and forward velocity was developed while a feed-forward ANN (artificial neural network) with standard BP (back propagation) algorithm was adopted to create a supervised model [10]. Two approaches of ANN and regressive support vector machine were practiced to model the energy dissipation of off-road vehicles whiled the controlled indoor testing facility of soil bin equipped with a single-wheel tester was employed reporting the satisfactory and robust performance of artificial intelligence tools [11]. The use of multi-criteria optimization models to assess the energy waste of off-road vehicles also showed good results and the potentiality of applying DEA (data envelopment analysis) and hybrid statistical-mathematical modeling approach of RSM (response surface methodology). It was inferred that input-oriented option of DEA led to the mean efficiency of 0.4379 [12]. The role of rolling resistance as a prominent factor was investigated as affected by the effect of tire inflation pressure, forward velocity and wheel load in controlled condition of a well-equipped soil bin facility utilizing a single wheel-tester. The experimental results were analyzed using ANOVA (analysis of variance) and development of multiple regression analysis based model using the stepwise selection technique and the obtained results showed that increase of velocity resulted in an increase of energy loss while increase of wheel load had the greatest effect on the increase of the energy loss [13]. The ANFIS (adaptive neuro-fuzzy inference system) with different membership functions was used to model the drawbar pull energy as affected by the tire parameters of velocity at three levels of 0.8, 1 and 1.2 m/s, wheel load at three levels of 2, 3 and 4 kN and slip at three levels of 8, 12 and 15% indicating that drawbar pull energy is a direct function of wheel load, velocity and slippage. Hence, the greatest value of 1.056 kJ corresponded to the wheel load of kN, slip of 15% and velocity of 1.2 m/s [14]. In the case of off-road vehicle traversing over terrain irregularities, a comparative study between artificial neural networks and support vector regression for modeling of the dissipated energy through tire-obstacle collision dynamics has been carried out. The tests were performed in a soil bin facility equipped with a single wheel-tester is employed considering input parameters of wheel load, speed, slippage, and obstacle height each at three different levels and in the next step, the potential of classic artificial neural networks was appraised against support vector regression with the two kernels of radial basis function and polynomial function [15].

To the best knowledge of the authors, little is dedicated to the evaluation of the net traction provided power at soil-wheel interface. Moreover, the use of indoor laboratory condition with a soil bin facility and a single-wheel tester served as a catalyst to arrive at more sensible and accurate experimental results. Owing to the nonlinear and complex nature of soil-wheel interaction process, this study advantages the adoption of capability of global searching of genetic algorithm with the local searching of ANN method to provide a robust and pivotal modeling approach. The present study spearheads the required power estimation for the driving wheels of off-road vehicles while the experimental test conduction in a controlled soil bin facility using single-wheel tester and adoption of soft computing tools are of the highlights and added values of the paper.

2. Materials and method

2.1. Assumptions and materials

The experimental tests of off-road vehicles are either performed as field tests or indoor laboratory condition. The indoor tests take advantage from the controlled soil bin condition which enables to achieve more reliable and accurate results. To this end, the capacious soil bin facility of Urmia University was used with a single-wheel testing rig attached to a carriage system inside the soil bin (see Fig. 1). The soil bin measures 24 m in length, 2 m in width and 1 m in depth. The single-wheel tester accommodates a driving tire of 220/65R21 model through a U-shaped frame. A load cell with the capacity of 2000 kgf is situated vertically between the U-shaped tester and an L-shaped frame which is connected to the carriage system. The load cell is responsible to measure the dynamic load exerted on the wheel while trafficking. The tester is also pivoted to the carriage by means of four horizontal arms each of which accommodates a load cell with the capacity of 500 kgf Bongshin model BS722. The longitudinally oriented load cells are responsible