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A comparative study between artificial neural networks and support vector regression for modeling of the dissipated energy through tire-obstacle collision dynamics

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ABSTRACT

Energy dissipation control has long been synthesized addressing the trafficking of wheeled vehicles. Wheel-obstacle collision has attracted the studies more on ride comfort, stability, maneuvering, and suspension purposes. This paper communicates, for the first time, the energy dissipation analysis through tire-obstacle collision that frequently occurs for the wheeled vehicles particularly those of off-road vehicles. To this aim, 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. 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. On account of performance metrics, it was revealed that radial basis function based support vector regression is outperforming the other tested methods for the prediction of dissipated energy through tire-obstacle collision dynamics. The details are documented in the paper.

1. Introduction

The investigation on energy conservation particularly that of vehicle trafficking has long been considered by researchers and the governments. A great portion of energy loss corresponding to the traversing of wheeled vehicles is that of trafficking on unpaved surfaces due to the forces and torques exerted to the wheel. The tire-soil interaction determines the mobility of the vehicle and then characterizes its dynamics [1]. Rolling resistance as an important parameter affecting vehicle mobility has a significant role in the optimization of fuel consumption [2]. A well-documented study in the literature indicated that about 20–55% of the energy developed to the drive tractor wheels is wasted in the tire–soil interaction [3]. This is an alerting statistic to reveal the importance of energy dissipation within the realm of Terramechanics. Mobility progression and enriched fuel efficiency of off-road vehicles are contradictory technical problems to be simultaneously achieved [4]. Road irregularities bring about significant impact exerted to the wheel in the vertical, longitudinal and lateral directions which can result in a substantial energy loss. In this regard, wheel-obstacle collision aggravates the problem in terms of greater tire deformation, wheel displacement and the induced vibrations. For the off-road vehicles such as agricultural tractors, where the great mass of vehicle added with the fact that there is no suspension system, the issue of energy loss is more serious. The following literature survey gives a brief account of investigations performed on energy loss in the scope of terrain vehicles.

A study including mathematical analysis, computational results, and experimental data related to the multi-wheel drive vehicle energy/fuel efficiency and vehicle tractive and velocity operational properties evaluation was carried out based on power distributions to the drive wheels [5]. This led to another study to assess and provide energy and, accordingly, fuel efficiency of multi-wheel drive vehicles [6], and it was concluded that the energy efficiency relies on the distribution of power between the wheels which affects not only the vehicle's slip efficiency, but also the mechanical efficiency of the driveline system that should be taken into account in design [6]. There are studies documented in the literature concerned with the analysis of energy loss of off-road vehicles but given the attention to the rolling resistance rather than considering the role of road irregularities. In Ref. [7], the prediction of energy

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efficiency indices of driven wheels (i.e. traction coefficient and tractive power efficiency) as affected by wheel load, slippage and forward velocity was carried out using (artificial neural networkANN) approach with the report on the considerable potential of the ANN method. In Ref. [8], energy dissipation due to motion resistance, as the most prominent performance index of towed wheels was assessed and a model for the prediction of energy loss in soil working machines was developed using the datasets obtained from a soil bin facility and a single-wheel tester. The energy use efficiency of soil-wheel interaction in a soil bin testing facility was addressed including the input parameters of velocity, tire inflation pressure, and wheel load were included while the potential of nonparametric technique of DEA (data envelopment analysis) and hybrid statistical-mathematical modeling approach of RSM (response surface methodology) were synthesized [9]. The experimental tests were also performed in an indoor soil bin testing condition to evaluate the energy loss of driven wheel as affected by some tire parameters wherein the experimental results were analyzed using ANOVA (analysis of variance) and the development of multiple regression analysis based model using the stepwise selection technique showed satisfactory results on the meaningfulness of input parameters on the objective parameter [10].

A survey was carried out to assess the effect of tire parameters on the variations of wheel load and vibrations transmitted from the ground to the tractor rear axle. Vertical wheel load of the left and right rear wheels were measured by means of strain-gage-based transducers [11]. A mathematical modeling attempt was undertaken for vehicle traversing over an obstacle and proposed an analytical tool for determining the obstacle height that the wheel can overcome the instability [12]. Collision of automobile wheels with a vertical obstacle was performed and the required force and the minimal speed of driving for disassembling of the tire from the wheel rim after the collision with an obstacle were determined [13]. Analytical and experimental efforts for an off-road vehicle ride dynamics model was also performed while the random roughness properties of the two parallel tracks of terrain were analyzed in view of equivalent undeformable terrain [14]. Open literature exists with some other studies given the attention to the vehicle dynamics of the wheels traversing over uneven surfaces [15].

As far as our literature review is concerned, there is no study dedicated to the synthesis of energy dissipation during wheel-obstacle collision. This paper also communicates the influence of obstacle height, wheel load, slippage, forward speed considering the obstacle geometry. A well-equipped soil bin facility including single-wheel tester for the provision of accuracy and control over the experiment is adopted. What is more, comparative modeling approaches are undertaken with a certain level of confidence, which can map the irreversibility data on the fitting line.

2. Materials and method

The vertical and longitudinal induced forces at wheel-obstacle collision were measured. The wasted power was accordingly measured as following:

$$P = \frac{F \times dx}{dt} = F \times V \tag{1}$$

where P is power (W), F is force (N) with vertical and longitudinal components, and V is forward speed (m/s). Hence, the dissipated energy is computed:

$$E = \int P dt \tag{2}$$

By substituting Eqs. (1) and (2);

$$E = \int FV\, dt \tag{3}$$

However, velocity should be presented as a vector in both vertical and longitudinal directions:

$$\vec{V} = \dot{x}i + \dot{y}j \tag{4}$$

The path of wheel is affected by the obstacle geometry as following:

$$y = sin\frac{2\pi}{l}x \qquad 0 < x < 2\pi \tag{5}$$

For the triangular shaped obstacle, the following equation is described:

$$y = \begin{cases} ax & x < \dfrac{l}{2} \\ -ax & x > \dfrac{l}{2} \end{cases} \tag{6}$$

where l is the obstacle length and a is 0.4, 0.6, and 0.8 for the obstacles with the heights of 1, 2, and 3 cm, respectively.

The availability of controlled testing condition is crucially significant for the reliability of the results. Hence, a SWT (single wheel-tester) inside a soil bin facility was used to conduct the required experiments. The soil bin channel with 24 m length, 2 m width and 1 m depth was filled with the soil texture predominant in the test region. The soil bin includes a channel, SWT and a carriage. The SWT was connected to the carriage to be able to traverse through the soil bin channel. The carriage was powered with a 22 kW electromotor which was connected to the inverter for the start/stop and velocity control processes. The power transmission was carried out by means of the electric motor to the chain system. The carriage was traveling in the channel using four ball bearings situated on the sidewalls of the soil bin. The SWT was connected to the carriage through an L-shaped part and also four horizontal arms each accommodating one S-shaped Bongshin load cell with 500 kgf capacity. The horizontal load cells were used to measure the horizontal forces applied to the wheel. One U-shaped frame was used to hold the tire and a three-phase electromotor of 5 kW was used to power the driving wheel. An appropriate inverter was also used to control the rotational velocity delivered to the wheel shaft and therefore; the linear velocity was adjustable. It is worth mentioning that the linear speed difference between the carriage and the SWT yielded different levels of adjustable slippage. Furthermore, the SWT was connected to the L-shaped frame by a power bolt rod (to adjust the applied wheel load) which was connected to a vertically situated S-shaped load cell responsible to measure the load variations while traversing over the obstacle and irregularities. The load cells were connected to Bongshin digital indicators which were in connection with a data logger with RS232 output signals. The data were subsequently sent to the laptop computer to be stored and processed with the frequency of 30 Hz. The general soil bin facility along with the single-wheel tester is shown in Fig. 1.

For all the experiments the tire inflation pressure was maintained at 131 kPa. Two shapes of triangular and curved obstacles were used in the study each at three heights of 1, 2 and 3 cm while two wheel load levels of 1 and 2 kN were considered. Furthermore, two levels of slippage were induced at 10 and 20%. Three forward velocities for the carriage were planned at three levels of 1.08, 1.8 and 2.52 m/s. The physical properties of the soil inside the soil bin are presented in Table 1. A wooden board with 2 m in width and 3 m