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# Wavelet neural network applied for prognostication of contact pressure between soil and driving wheel

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ABSTRACT

This paper describes the measurement of contact pressure in the context of wheel–terrain interaction as affected by wheel load and tire inflation pressure when fusion of the wavelet transform with the back-propagation (BP) neural network is applied to construct the wavelet neural network contact pressure prediction model. To this aim, a controlled soil bin testing facility equipped with single-wheel tester was utilized while three levels of velocity, three levels of slippage and three levels of wheel load were applied. Using image processing technique, contact area values were determined which were subsequently used for quantification of contact pressure. Performances of the different predictor models incorporated of various mother wavelets were evaluated using standard statistical evaluation criteria. Root mean square error and coefficient of determination values of 0.1382 and 0.9864 achieved by the optimal wavelet neural network are better than that of BP neural network. The proposed tool typifies a high learning speed, enhanced predicting accuracy, and strong robustness.



## 1. Introduction

The increasing global demand for food owing to the growing population rate makes the adoption of mechanized agriculture an unavoidable step in farming procedures. Multiple traversing of agricultural wheeled vehicles in order to perform various processes along with the augmented size of the pertinent vehicles has put added stresses on the soil beneath the traversing tire. The interaction between the wheel and soil drastically influences the soil physical characteristics thorough contact pressure which forms the unwanted soil compaction. The disadvantages of the soil compaction have already been covered in the literature frequently [1,2]. Contact area plays a strong role in the determination of the contact pressure and thus in the formation of soil compaction [2]. In Ref. [3], the effect of soil structure and physical properties was reported to be effective on determination of contact pressure, however, on non-compacted soil, peak pressures are equal to that of the inflation pressure. In [4], dynamic load and inflation pressure effects on contact pressures of a tire were evaluated on a firm clay soil. As an index of induced pressure at soil–tire interface, vertical stress propagation in a soil profile was performed as affected by tire size, inflation pressure and wheel load [5]. For instance, soil stress at topsoil

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part, as a direct function of contact pressure, was assessed under the effect of wheel load and tire inflation pressure with the wheel loads of 11, 15 and 33 kN at inflation pressures of 70, 100 and 150 kPa [6]. Although the attempts on determination of contact pressure have both been performed experimentally and analytically, the resultant data should be processed for developing a model that has the considerable capability to be applied with satisfactory accuracy. Due to the stochastic nature of machine dynamics and nonlinear behavior of soil, the soil–wheel interaction is considered a highly complex and sophisticated problem to be modeled and therefore, diverse methodologies of artificial intelligence are advised [7–9].

As far as our literature review is concerned, there is no study dedicated to the prognostication of the wheel–soil contact pressure by employing wavelet neural network. Furthermore, the experimental dataset are obtained from series of tests in controlled soil bin facility environment. The hypotheses below are outlined in the present study as following.

i. Wheel load, velocity and slippage, as tire parameters, affect the contact area and thus contact pressure.
ii. Artificial neural network and wavelet neural network, as stochastic modeling tools, are suitable candidates to perform the modeling of contact pressure of driven wheel under the effect of input parameters.

## 2. Materials and methods

A soil bin facility was used due to provision of a controlled condition for carrying out the experiments. A single-wheel tester was used in the soil bin facility. The holistic system consists of the bin frame which accommodates the other components added with the soil mass. A 220/65R21 driven tire is situated in a U-shaped chassis that is connected to the L-shaped frame through four horizontal arms. This configuration improves the dynamic stability of the wheel while traversing. The wheel tester is attached to the carriage as a significant part in the soil bin facilities. The carriage is powered for pulling the single-wheel by an electromotor with the power of 22 kW at the nominal rotational speed of 1457 rpm was applied. Furthermore, a SV 220IS5-2 NO, 380 V model of LG inverter (brand LS) for rotational speed of the engine was applied that gave speed control for the carriage with application of chain system. An induction motor of 5 kW, 3-phase, 1430 sync rev/min was applied to provide driving power for the wheel. The difference between the velocity imposed to the single-wheel tester and the carriage velocity denoted various and desired slippage levels. The load cell was vertically positioned between the wheel U-shaped chassis and L-shaped frame in a series with a power bolt. Rotation of the power bolt applied the desired wheel load and the load cell transmitted data to a separated Bongshin digital indicator BS722 model connected to a data logger thorough a RS232 port where data were simultaneously stored in a laptop computer. In this study, a clay loam soil texture was selected as the predominant soil type of test location, Urmia city, Iran. General soil bin system is depicted in Fig. 1 where the experiment framework and soil constituent properties are detailed in Table 1 and Table 2, respectively.

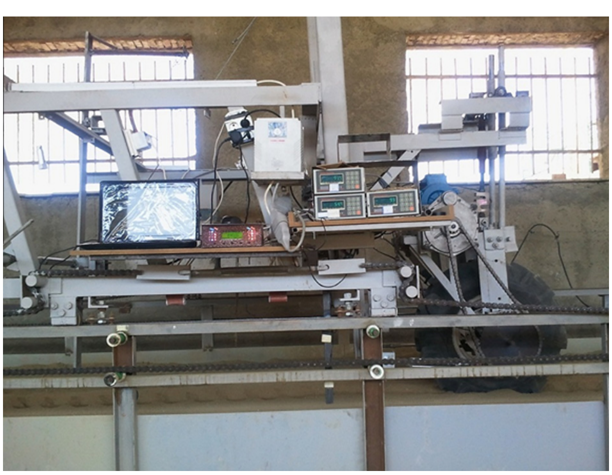

**Fig. 1 – The general soil bin facility used for the experiments.**

A new method was performed to calculate contact pressure in this study by application of image processing method. A white color powder was used at soil–tire interface for each treatment and the images were taken simultaneously. A Panasonic LUMIX DMC TZ25 camera was used for this purpose at a constant distance while a $4 \times 4$ cm index was used for calibration. The images were taken in RGB environment where illumination is combined with color that a small change in color space could change the color of image remarkably. Therefore, it is necessary to use a space that color and illumination are separated. Using s (saturation) component in HSV color space and b component in LAB space, a preferred separation of tire track and background was achieved. First, the components were normalized in the range between 0 and 1. For improving the separation, the Gamma transform was applied as following.

$$x_1 = (s + v) \quad (1)$$

**Table 1 – Summary of experiment conducted.**

| Independent parameters | | | Dependent Parameter |
|---|---|---|---|
| Wheel load (kN) | Slippage (%) | Velocity (m/s) | |
| 2 | 8 | 0.8 | |
| 3 | 12 | 1 | |
| 4 | 15 | 1.2 | Contact pressure (kPa) |

**Table 2 – Soil constituents and its measured properties.**

| Item | Value |
|---|---|
| Sand (%) | 34.3 |
| Silt (%) | 22.2 |
| Clay (%) | 43.5 |
| Bulk density (kg/m$^3$) | 2360 |
| Frictional angle (°) | 32 |
| Cone index (kPa) | 700 |