Fuzzy logic system based prediction effort: A case study on the effects of tire parameters on contact area and contact pressure

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ARTICLE INFO

ABSTRACT

Various methodologies of artificial intelligence have been recently used for estimating performance parameters of soil working machines and off-road vehicles. Due to nonlinear and stochastic features of soil–wheel interactions, application of knowledge-based Mamdani max–min fuzzy expert system for estimation of contact area and contact pressure is described in this paper. Fuzzy logic model was constructed by use of the experience of contact area and contact pressure utilizing data obtained from series of experimentations in soil bin facility and a single-wheel tester. Two paramount tire parameters: wheel load and tire inflation pressure are the input variables for our model, each has five membership functions. As a fundamental aspect of the fuzzy logic based prediction systems, a set of fuzzy if-then rules were used in accordance with fuzzy logic principles. 25 linguistic if-then rules were included to develop a complicated highly intelligent predicting model based on Centroid method at defuzzification stage. The model performance was assessed on the basis of several statistical quality criteria. Mean relative error lower than 10%, satisfactory scattering around unity-slope line (T), and high coefficient of determination, R^2, were obtained by the fuzzy logic model proposed in this study.

1. Introduction

1.1. Literature review

Significant upsurge in global population increases food demand which results in mechanized agricultural practices. Heavy tillage practices, multiple passages, and giant wheeled vehicles traversing are of major sources of topsoil and subsoil compaction. Estimation of tire contact patch area contributes to determination of contact pressure and stress-strain propagation that are compaction originators [1]. Soil stress with its lateral production (i.e. soil compaction) is function of contact area [2]. Therefore, estimation of contact area as a major factor influencing the area of soil compaction and further soil–wheel interaction parameters has to be obtained precisely. Although data on soil–tire interface contact area for modern tires and the experimentations carried out are insufficient [3], contact area measurements have been conducted by many researchers for conventional tractors [4,5].

Role of contact area on contact pressure should also be considered as the area of contact in which load is applied to soil that forms contact pressure. Various investigations in literature have mentioned tire inflation pressure and wheel load as the main influential parameters on formation of contact pressure [2]. Diserens [6] explored a wide range of tires and reported contradictory results for the effect of inflation pressure on the contact area and concluded that inflation pressure had negligible effect on the contact area. Several researchers declared an increment of contact area with respect to decrement of inflation pressure [3]. The effect of wheel load on contact pressure is less clear while the effect of inflation pressure has been noticeably confirmed [2].

1.2. Fuzzy logic method

Self-learning approaches are applied in software computations comprising statistics, machine learning, neural networks and fuzzy logics [7]. Artificial intelligence has featured as promising, instrumental and practical technique of soft computing technologies in science and engineering domains. Fuzzy logic deals with the concept of partial truth theory and provides a methodology to model uncertainty and the human way of thinking, reasoning and perception [8]. Fuzzy logic systems are rule-based or knowledge-based systems first formulated by Zadeh [9]. Since the fuzzy set, a class of objects with a continuum of grades of membership, is descriptive of vague impressions than numerical, variables are therefore better described by linguistic terms. Fuzzy logic sets are characterized by membership functions, also known as characteristic functions that

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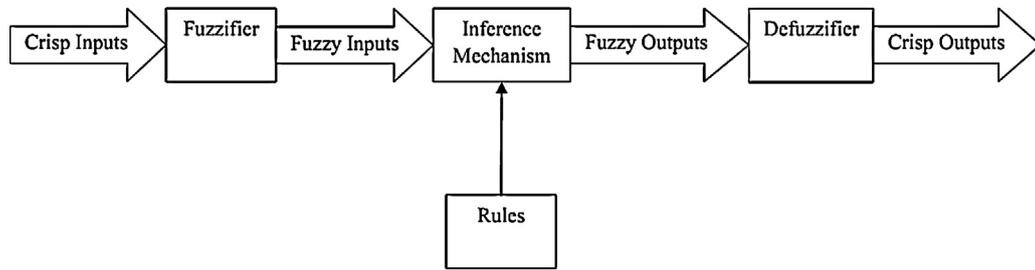
Fig. 1. A general framework of the fuzzy logic system.

assign to each object a degree of membership varying between zero and one. Variety of membership functions are in practice such as S-shaped, Z-shaped, Triangular, and Trapezoidal shaped functions. The triangular membership functions are formed using straight lines. These straight line membership functions have the advantage of simplicity. Because of their smoothness and concise notation, Gaussian membership functions are popular methods for specifying fuzzy sets. These curves have the advantage of being smooth and nonzero at all points [10].

- This spline-based function of x is so named because of its Z-shape. The parameters a and b locate the extremes of the sloped portion of the curve as given by.

$$f(x; a, b) = \begin{cases} 1; & x \leq a \\ 1 - 2\left(\frac{x-a}{b-a}\right)^2; & a \leq x \leq \frac{(a+b)}{2} \\ 2\left(\frac{x-b}{b-a}\right)^2 & \frac{(a+b)}{2} \leq x \leq b \\ 0; & x \geq b \end{cases} \quad (1)$$

- Triangular-shaped built-in membership function. The triangular curve is a function of a vector, x, and depends on three scalar parameters a, b, and c, as given by:

$$f(x; a, b, c) = \begin{cases} 0; & x \leq a \\ \left(\frac{x-a}{b-a}\right); & a \leq x \leq b \\ \left(\frac{c-x}{c-b}\right) & b \leq x \leq c \\ 0; & c \leq x \end{cases} \quad (2)$$

Or closely by

$$f(x; a, b, c) = \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right) \quad (3)$$

where the parameters a and c locate the "feet" of the triangle and the parameter b locates the peak.

- The symmetric Gaussian function depends on two parameters σ and c, listed in order in the vector [sig c], as given by:

$$f(x; \sigma, c) = e^{-(x-c)^2/2\sigma^2} \quad (4)$$

A fuzzy logics system (FLS) consists of four main steps as briefly defined: (a) Fuzzifier that converts numerical input values to fuzzy sets, (b) Rules that are the heart of FLS and are described commonly by if-then true rules, (c) Inference to combine rules and map input variables to output variables, and (d) Defuzzifier to reconvert the outputs of inference stage to crisp output values. Fig. 1 shows a general framework of fuzzy logic system.

The advantage of Fuzzy based systems is nonlinear mapping, computational flexibility and accurate estimations that make it applicable to be used as a reliable alternative modeling technique

in engineering [9,11]. To the best knowledge of authors, literature is poor regarding the investigation of the effects of tire inflation pressure and wheel load on contact area and contact pressure predicted by a constructed fuzzy rule-based approach on the basis of Mamdani max–min technique. The readily available data samples obtained from soil bin facility were used for FLS developed model.

2. Research method

2.1. Experimental phase

A capacious soil bin facility was designed and constructed in 2010 in the Faculty of Agriculture, Urmia University, Iran. This soil bin features 23 m length, 2 m width and 1 m depth [12]. This long channel could accommodate a carriage, a single-wheel tester, and tillage tools. A three-phase electromotor of 30 hp was used to move the single-wheel tester, mounted on carriage, by use of chain system. The carriage had the ability to traverse at anydesired speed of between 0 and 20 km/h. The system set up is shown in Fig. 2. A load cell of 20 kN capacity was situated vertically between the single-wheel tester and power bolt to measure the value of vertical loading. Data were sent to a digital indicator and then to a data logger device. Transmitted files were recorded with txt files format and subsequently were imported to MATLAB software (version 7.6, 2008, Mathworks Company) for being processed. Summary of treatments being tested is shown in Table 1. In order to determine contact area experimentally, at each treatment, white powder was spread on periphery of soil–tire interface to define contact area. A digital camera was used to take images of contact areas. Image processing method was then used to define contact area.
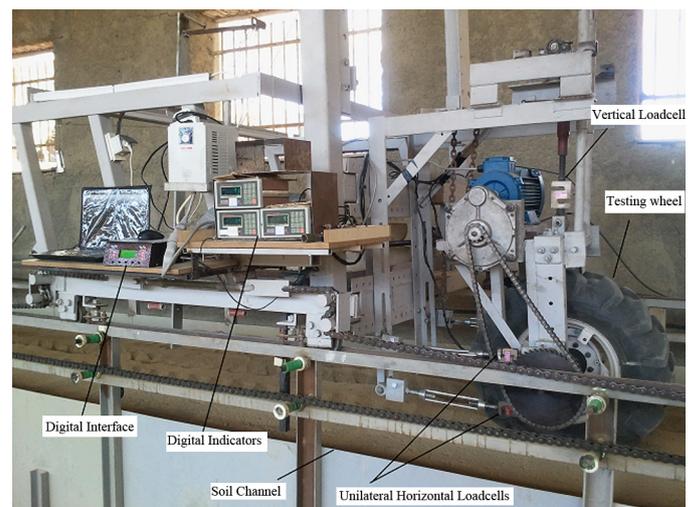

Fig. 2. General depiction of the soil bin system setup for experimental phase of study.