Measurement 63 (2015) 232–239

Contents lists available at ScienceDirect

Measurement

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

Stiffness performance of polyethylene terephthalate modified asphalt mixtures estimation using support vector machine-firefly algorithm

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A R T I C L E   I N F O

Article history:
Received 1 October 2014
Received in revised form 17 November 2014
Accepted 27 November 2014
Available online 13 December 2014

Keywords:
Firefly algorithm
Support vector machine
Pavement performance
PET modified asphalt mixtures
Environmental conditions
Estimation

A B S T R A C T

Predicting asphalt pavement performance is an important matter which can save cost and energy. To ensure an accurate estimation of performance of the mixtures, new soft computing techniques can be used. In this study, in order to estimate the stiffness property of Polyethylene Terephthalate (PET) modified asphalt mixture, different soft computing methods were developed, namely: support vector machine-firefly algorithm (SVM-FFA), genetic programming (GP), artificial neural network (ANN) and support vector machine. The support vector machine-firefly algorithm (SVM-FFA) is a metaheuristic search algorithm developed according to the socially dashing manners of fireflies in nature. To develop the models, experiments were performed. The process, which simulates the mixtures' stiffness, was created with a soft computing method, the inputs being PET percentages, stress levels and environmental temperatures. The performance of the proposed system was confirmed by the simulation results. Soft computing methodologies show very good learning and prediction capabilities and the results obtained in this study indicate that the SVM-FFA contributed the most significant effect on stiffness performance estimation since the SVM-FFA model had a better correlation coefficient than the SVM, ANN and GP approaches. R^2 and RMSE were utilized for making comparisons between the expected and actual values of SVM-FFA, GP, ANN and SVM. The proposed SVM-FFA methodology predicted the output values with 254.4743 (mm/day) and 0.9957 RMSE and R^2 respectively.

1. Introduction

Improving asphalt mixture properties is the aim of engineers and experts in order to increase the service life of asphalt pavement. Using additives such as various types of fibers and polymers is a common way of improving asphalt mixture characteristics [1].

Recycling asphalt pavement can save a lot of resources and protect the environment. Currently, more and more researchers are paying attention to the exploration and application of recycling technology. In this case, polymer modification offers the opportunity to conquer the deficiencies of asphalt and thereby improve the performance of bituminous mixtures. The construction of pavement structure with modified characteristics that can offer

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http://dx.doi.org/10.1016/j.measurement.2014.11.022
0263-2241/

better performance as well as longer service life is one of the goals of road engineers and designers. Hence, many studies have been previously performed to evaluate asphalt pavement performance with modified characteristics [2–7]. However, although using virgin modifiers in road pavement can improve pavement properties, in many cases it incurs higher financial costs. Therefore, much research has focused on using modifiers obtained from waste materials to reduce costs imposed by using virgin modifiers and finding solutions to reuse post-consumed materials as secondary materials in road construction projects in environmentally friendly ways [8–14].

Stone matrix asphalt (SMA) is hot mix asphalt (HMA) with a coarse aggregate structure and high asphalt content. Stone matrix asphalt was developed in Germany in the 1960s and provides better resistance against permanent deformation [15]. SMA has several advantages over conventional dense-graded asphalt mixture including: high rut resistance, high durability, improved resistance to reflective cracking, high skid resistance, better drainage conditions and reduced noise pollution [16,17].

The prediction of asphalt pavement performance is a significant issue that can lead to saving cost and energy. To ensure an accurate estimation of the performance of mixtures based on environmental conditions, new soft computing techniques can be utilized [15–19]. Collecting input/output data pairs and learning the proposed network from these data is the main idea behind soft computing methodologies.

Soft computing techniques are a popular means of exploring and presenting interactions between parameters affecting one phenomenon. The use of such methodologies in pavement engineering is increasing because they assist road engineers and designers to gain a better perspective about pavement performance parameters.

The Support Vector Machine (SVM) is an exceptional soft computing learning technique, which has been used in different applications in the fields of environmental research, computing and hydrology [15–19]. Additionally, various applications have been found in classification and regression analysis, pattern recognition, and forecasting, which perform better than recently developed techniques, e.g. conventional neural network methodology and other statistical analysis models [20–25]. Recently, SVM has proved its performance in solving forecasting problems [26–28].

A study was recently performed [29] to estimate the flow number of dense asphalt-aggregate mixtures using the SVM. The investigation revealed that the SVM was capable of predicting the flow number of asphalt mixtures. Similarly, another study employed the SVM method to model the mechanical properties of hot-mix asphalt (HMA). This study showed that the SVM's prediction performance is far better than multivariate regression-based models and comparable to the ANN [30].

Furthermore, in 2010 an efficient off-line nonlinear pavement back calculation system was introduced using Support Vector Machines (SVM). In this study, a comparison was performed with another common machine learning technique, the multi-layer perceptron (MLP). The results indicated the effectiveness of the SVM method over other methods [31]. Moreover, a new road friction coefficient estimation method based on the SVM was proposed in the application of steering driving under a variety of road conditions. The results presented in the study showed that the SVM can accurately calculate the friction coefficient, which is important for controlling the stability of a vehicle that is over or under steering [32]. In another application of the SVM method, a signal processing algorithm based on the principle of the support vector machines characteristic of road surface malfunctions was developed. The test results proved that this algorithm can be used to detect pavement malfunctions with high efficiency [33].

In the current study, an estimating model is developed to predict the stiffness property of Polyethylene Terephthalate (PET) modified asphalt mixtures based on a series of environmental conditions using SVM coupled with the Firefly Algorithm (FFA). Subsequently, the performance of SVM-FFA for estimating the stiffness property of PET modified asphalt mixture is investigated. PET obtained from waste PET bottles served as a modifier. FFA was utilized to determine the SVM factors. Besides, it was aimed at analyzing the efficiency of SVM, ANN, SVM-FFA, and genetic programming in order to estimate the stiffness property of PET modified asphalt mixture based on a series of test conditions.

2. Background of soft computing techniques in pavement engineering

This section presents an overview of studies which have used soft computing techniques in pavement engineering over the past few years.

In this regard, neuro-fuzzy can be employed to calculate pavement moduli with present input–output data articulating the target behavior [34]. Correspondingly, an adaptive neuro-fuzzy inference system (ANFIS) can be utilized to back calculate asphalt mixture moduli. Fuzzy inference is not appropriate for substantial numbers of input–output patterns and input space partitioning. Nevertheless, it can be a good alternative for a small amount of training data relating to a considerable amount of uncertainty [35].

Training data may involve either in situ or synthetic pavement moduli. The training procedure can be carried out by either experimental records to describe particular test conditions or by synthetically collected records to inversely simulate the pavement response model. The primary advantages of the adaptive back calculation technique are the real-time back calculation capability and accurate results [36].

HMA modelling as a linear viscoelastic material helps to find the stress–strain performance as well as resilient modulus of HMA mixtures. The relative amount of rest period to loading time (R/D) of 4 can produce about 8% error in predicting the resilient modulus of HMA under square waveform. The theory of resilient modulus master curve could be used effectively for modelling the resilient modulus of asphalt concrete mixtures at different loading frequencies and elevated temperatures [37].

Bianchini and Bandini [38] evaluated a neuro-fuzzy model to estimate the performance of flexible pavement.