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A smart force platform using artificial neural networks

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ABSTRACT

The human body may interact with structures and these interactions are developed through the application of contact forces, for instance when walking. The aim of this paper is to propose a new methodology using Artificial Neural Network (ANN) for calibrating a force platform in order to reduce the uncertainties in the values of estimated vertical Ground Reaction Force and the positioning of the applied force in the human gait. Force platforms have been used to evaluate the pattern of human applied forces and to fit models for the interaction between pedestrians and structures. Linear relation assumptions between input and output are common in traditional Least Mean Square methods used in calibration. Some discrepancies due to nonlinearities in the experimental setup (looseness, wear, support settlements, electromagnetic noise, etc.) may harm the overall fitting. Literature has shown that nonlinear models, like ANN, can better handle this. During the calibration, the input data to the ANN were the reference voltages applied to the Wheatstone bridge, while the output data were the values of the standard weights applied in the force platform in defined sites. Supervised training based on *k*-fold cross validation was used to check the ANN generalization. The use of ANN shows significant improvements for the measured variables, leading to better results for predicted values with low uncertainty when compared to the results of a simple traditional calibration using Least Mean Squares.

1. Introduction

Several cases of excessive vibration of footbridges in a vertical direction due to human-induced loads have been reported, being usually related to crowd conditions. Until recently, the load due to a pedestrian acting on the structure has been obtained from investigations in platforms, gait machines or even prototype footbridges, in which the applied force is the amount produced by a single walking pedestrian. For groups of pedestrians or crowds, a combination of these individual applied forces is considered. The design load is, thus, a force model. However, attention is drawn to some recent publications [1–3] regarding the potential effect of the dynamic interaction between pedestrians and structures while crossing footbridges in a crowd situation. So, the correct measurement and modelling of such load effects is essential for a better understanding of the interaction process.

Force plates or platforms are devices designed to measure the forces exerted by a body in a contact surface usually called Ground Reaction Forces (GRF). Accurate measurements of GRF on force platforms are important in many areas of biomechanics' research, mainly on those concerned with the magnitude of the applied force and its location. These errors can be significantly reduced by performing a suitable calibration of the used devices. Using reference values of applied loads in the vertical direction, for instance magnitude and position, the calibration can be performed to reduce the uncertainty in the measurements. The process is not meant to overcome modelled processes in the behaviour of the force platform like clearances, non-linear behaviour of the material, friction, variability in dimension and material properties that were not taken into account in the design stage. Sometimes these deviations from the expected behaviour are small, so the uncertainty comes mainly from random uncertainty, which means the calibration will just access the systematic errors. But even in measurement systems with low random uncertainty, the calibration cannot completely access systematic errors mainly due to the non-linear behaviour of the complete system (transducers, load cells, metallic plates, boundary conditions, signal conditioners, amplifiers) that can cause, for example, different sensitivity along the service range. In this case, an expert system that can manage the behaviour of the measurement system in all the service range is desirable.

In this context, Ref. [4] presented a real-time procedure based on Artificial Neural Networks acting as a filter to predict the final values of weighting systems. The proposed method required the

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order of the sensor to be defined beforehand and allowed real time evaluations of predicted final values of weighting systems that were still oscillating. The results showed accurate predictions of the final value of the weight in less than one and a half periods of oscillation of the output signal.

In a different way, Refs. [5,6] applied an Artificial Neural Network (ANN) to calibrate load cells by strain gages. The ANN was used as an interpolation tool, having as input, the reference voltage of a Wheatstone bridge and as output the weight standard was used directly to generate the load cell deformation. Ref. [6] affirms that satisfactory results were obtained using a 5-3-1 feedforward ANN architecture trained by the backpropagation algorithm and using Levenberg–Marquardt algorithm. In this last paper, care was taken in separating a set of data in order to validate and obtain the performance of the trained ANN. An MSE (Mean Square Error) of around 6% was obtained.

One of the first investigations in the use of a force platform to record data of Ground Reaction Forces (GRF) was reported by [7–9]. The last one even made use of a "ciné camera" to correlate the movements with the records. Ref. [10] used force platforms to record the data of the Ground Reaction Force (GRF). The authors affirm that using these raw data and Artificial Neural Networks it is possible to identify the human gait malfunction.

Refs. [11,12] used a Function Link Neural Network to compensate both linearity and temperature effects in a load cell. It was possible to improve the accuracy of the transducer using this technique. This network is basically a flat single network in which the need of hidden layers has been removed by incorporating just one layer with a functional expansion of the input pattern. The last reference reported that the accuracy of the load cell could reach the requirements for precision class C10 of the [13].

Applications of ANN to instrumentation and measurement are now relatively common in the industry [14]. Specifically in the area of weigh in motion systems, ANN has received special attention due to its nonlinear behaviour and fault tolerant capabilities which have generated a number of papers [15–18].

Refs. [19,20] used polynomial and MLP in combination in order to improve the MSE for the prediction of aerodynamic loads from load cells in wind tunnels. They found that the MSE value of the fitting substantially decreased as the complexity of the mathematical modelling of the polynomial increased, along with the number of neurons in the hidden layer. The improvements in the MSE errors were about 10–5%.

The GRF during running was studied by [21]. They investigated the potential of ANN and multiple linear regression models (MLR) in estimating GRF. MLR was implemented to model the relationship between source data and target data by fitting a linear equation to the observed data. However, due to ANN's flexible structure and many configurable internal parameters it was able to capture not only linear but also complex non-linear relationships. The concurrent implementation of the ANN and MLR models has enabled an assessment for the selection of the preferred model for the prediction of the three components of GRF. In the area of biomechanics, Ref. [22] suggested a feedforward backpropagation neural network model to estimate the resultant centre of mass (COM) trajectory in the sagittal plane. The input data of the neural network model developed were obtained using an AMTI force plate, model OR-6. The feedforward backpropagation neural network consisted of two layers. The first layer, or hidden layer, had a tangent sigmoid activation function, and the second layer, or output layer, had a linear activation function. The analysis indicated that neural network models provided promising results to estimate COM in clinical applications.

Recently, Ref. [23] studied the human gait using force plates, markers and cameras to predict joint moments by means of the inverse dynamics method. The purpose was suggesting a method to predict the GRF which occur in complex planes during asymmetric movements in a double support phase. This study used a feedforward network which had one input layer, one hidden layer and one output layer, to predict a single side FX, FY, FZ GRF of data. The learning process was trained with the gradient descent method that utilized a backpropagation algorithm. The bipolar sigmoid function was used as the transfer function between the layers. This study showed excellent results in agreement with measurements at a level of 0.99 of the correlation coefficient.

Generally speaking, the applications previously commented on show the advantages in using a smart methodology to deal with uncertainty in weighting measurements that can be accomplished, for instance, by means of ANN acting as a smart filter for the raw data in order to account for random uncertainty, as a smart data fitting, acting as a general non-linear regression tool, in order to account for systematic errors. The use of ANNs in the reviewed papers also revealed great promise in solving non-linear curve fitting problems and was the main reason for the investigation of its use in this paper. Despite this remarkable performance, it deserves a closer look for its adequacy as a surrogate method to the traditional calibration system.

2. Force platforms

Because it is sufficiently rigid, the force platform provides an electrical signal proportional to the applied force to the structure. In the design of the used platform only the vertical forces measurement was considered. Fig. 1 shows the instrumented platform and the acceleration and deceleration plates (not instrumented) that were only used to stabilize the pace and minimize the influence of fluctuations in the step cadence due to the subject's visual feedback. Fig. 2 shows structural details of the actual designed device [24].

When the pedestrian walks on the platform (left and right plates were instrumented, see Fig. 1), the force applied on it is measured by load transducers placed at the supports, which generates electrical signals that are amplified and recorded by a data acquisition system. These signals allow for the evaluation of the force position and intensity in each plate. In total, six ring-type load cells instrumented with strain gauges in a full Wheatstone bridge arrangement were used, three on each plate. Using this configuration, it is also possible to evaluate the step position. Each load cell had a diameter of 47 mm and length of 40 mm and was 2.2 mm thick. Fig. 3 depicts the left plate, intended to capture the left step force, with the corresponding load cells and their positions in relation to the origin of the (x,y) coordinate axes. The arrangement for the right hand side plate was similar to this. The signals from both plates were simultaneously acquired, so that

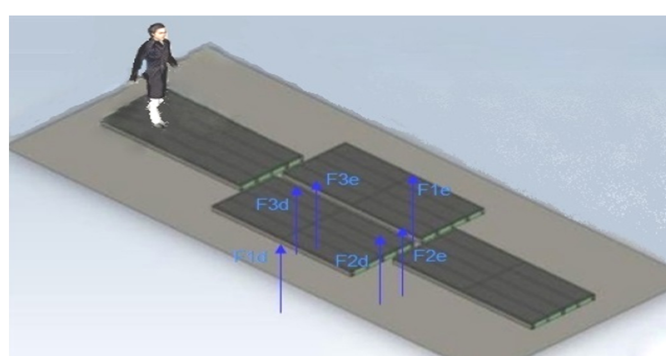

Fig. 1. Model of force platform for gait analysis (arrows indicate force reaction from load cells).