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Analysis of the influence of forestry environments on the accuracy of GPS measurements by means of recurrent neural networks

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ABSTRACT

The present paper analyses the accuracy of the measurements performed by a global positioning system (GPS) receiver located in forested environments. A large set of observations were taken with a GPS receiver at intervals of one second during a total time of an hour at twelve different points placed in forest areas. Each of these areas was characterized by a set of forest stand variables (tree density, volume of wood, Hart-Becking index, etc.) The influence on the accuracy of the measurements of other variables related to the GPS signal, such as the position dilution of precision (PDOP), the signal-to-noise ratio and the number of satellites, was also studied.

Recurrent neural networks (RNNs) were applied to build a mathematical model that associates the observation errors and the GPS signal and forest stand variables. A recurrent neural network is a type of neural network whose topology allows it to exhibit dynamic temporal behaviour. This property, and its utility for discovering patterns in non-linear and chaotic systems, make the RNN a suitable tool for the study of our problem.

Two kinds of models with different numbers of input variables were built. The results obtained are in line with those achieved by the authors in previous research using different techniques; they showed that the variables with the highest influence on the accuracy of the GPS measurements are those related to the forest canopy, that is, the forest variables. The performance of the models of the RNN improved on previous results obtained with other techniques.

1. Introduction

As is well-known, the *global positioning system* (GPS) is a space-based global navigation satellite system that provides reliable location and time information in all weathers and at all times, anywhere on or near the Earth when and where there is an unobstructed line of sight to four or more GPS satellites [1]. The GPS system was established in 1973 by the US Department of Defense (DOD) to overcome the limitations of previous navigation systems [2,3]. GPS satellites broadcast signals from space, which each GPS receiver uses to calculate its three-dimensional location (latitude, longitude, and altitude) plus the current time [4].

Although GPS was initially conceived to be used in open spaces, in practice many users operate GPS receivers in conditions such as forest environments where the signal reception is not so favourable. According to previous research, the presence

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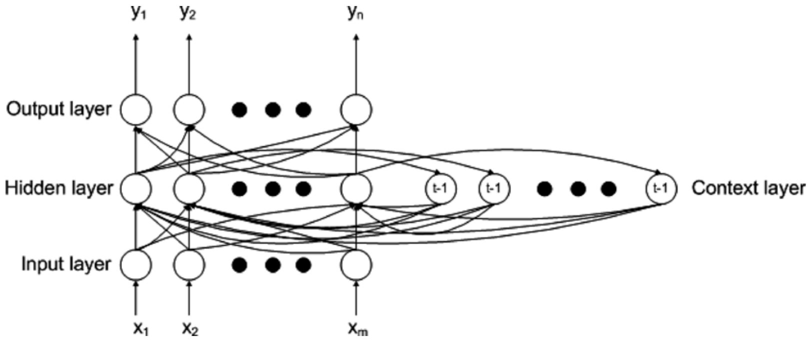

Fig. 1. Schematic representation of the Elman recurrent neural network.

of an overhead canopy may degrade the positional precision by one order of magnitude [5]. In the present work the impact of forest canopy on quality and accuracy of GPS measurements by means of recurrent neural networks is analysed with success. It must be stressed that the aim of the present research is to build a recurrent neural network able to predict the value of the variables H_{acc} and V_{acc} (horizontal and vertical accuracies) using as input variables all those listed in Section 4. This paper is in line with previous research focused on the use of GPS under a forest canopy [6–10].

2. The aim of the present research

As has been stated above, the aim of the present research is the prediction of the vertical and horizontal accuracies of the coordinates and the determination of which of the variables have the most important influence over them. The input variables that are used are the dasometric characteristics of the fields (i.e. arithmetic mean diameter, average height, crown height, stand density, etc.) together with the GPS signal variables (position dilution of precision, X accuracy, Y accuracy, vertical accuracy, horizontal accuracy, etc.) which are taken into account. The above-mentioned output variables and horizontal and vertical accuracies were calculated for each sample through the following expressions:

$$H_{acc} = \sqrt{(E_i - E_{true})^2 + (N_i - N_{true})^2} \tag{1}$$

$$V_{acc} = |Z_i - Z_{true}| \tag{2}$$

where H_{acc} and V_{acc} indicate horizontal and vertical accuracies, respectively. E_i, N_i and Z_i are the measured positions at the ith second, and E_{true}, N_{true} and Z_{true} are the true positions along the easting, northing and ellipsoidal height directions, respectively.

3. The mathematical model

3.1. Recurrent neural networks (RNNs)

In recent years, recurrent neural network techniques have been applied to a wide variety of problems. Such neural networks can be divided into two main categories: fully recurrent and partially recurrent neural networks. For the purposes of the present research, a kind of partially recurrent neural network called an Elman network [11] will be employed. Simple partially recurrent neural networks were introduced in the late 1980s [12] for learning strings of characters. Many other applications have been developed since then, and they can now be found in many different research areas such as linguistics [13], communication systems [14], electrical power load prediction [15] and stock market forecasting [16].

An Elman RNN is a network with an initial configuration based on a regular feedforward neural network. As is well-known, in a feedforward neural network the information moves in only one direction, forward, from the input nodes, through the hidden nodes and to the output nodes without cycles or loops. This is the main difference between the feedforward neural network and the Elman network, because the latter has a layer called the context layer. The neurons in the context layer, called context neurons, hold a copy of the outputs that are given by the neurons of the hidden layer to the output layer. This means that in the following computing step, information that was given as an output by the hidden layer is used as a new input information for this layer. Fig. 1 represents the architecture of the Elman recurrent neural network (please note that the neurons of the context layer are signalled with $t - 1$ inside in order to remark that, in the time t, they contain the information generated by the hidden layer in the time $(t - 1)$).

In the same way as in other neural network models, the strength of the relationships between neurons in an Elman RNN are indicated by weights. For this kind of neural network the weight values of the neurons are chosen randomly and their values are changed during the training in order to optimize them. There is only one exception to this rule: for the weights