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Neural Technologies For Increasing The GPS Position Accuracy

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Abstract – *Aim of this paper is to present a method to improve the accuracy of a GPS receiver. It is well known that there are many factors affecting the accuracy of a GPS receiver. In this work, the authors point out that many of these factors, considered in a given geographic area, have a certain periodicity. An important example of this kind of factors is the sky satellite position relative to receiver. The proposed method uses a neural network to correct the position computed by the receiver. The neural network is trained to learn the errors introduced into the measuring system by the cyclic phenomenon in the various hours of the day.*

Keywords *–GPS position accuracy, neural network*

INTRODUCTION

The Global positioning System (GPS) consists of constellation of continuously orbiting satellites run by the United States Department of Defense (DOD). There are two levels of positioning accuracy: Standard Positioning Service (SPS) using the Coarse/Acquisition (C/A) code signals and Precise Positioning Service (PPS). PPS is encoded and not accessible to civilian users. SPS was intentionally degraded to obtain an accuracy of 100m (95% probability). This error source was eliminated after May 1, 2000 [1].

A GPS receiver antenna detects signals from several of the DOD's NAVSTAR satellites at the same time. The receiver uses precise time and satellite position data, as well as other information in the transmitted signals, to calculate position coordinates. The time that the signal uses to travel from the satellite to the receiver is one of the important values that the receiver must calculate. The changeable atmospheric conditions, affecting how fast the signals travel, can cause small errors in the calculated coordinates. Under some conditions the receiver can get unclear signals from one or more satellites due to reflections of the same signals from water surfaces or buildings that are nearby (multipath). The most relevant factors affecting the GPS position accuracy are:

1. Satellite clock and position errors
2. Atmospheric delay of the transmitted satellite signals
3. Receiver noise and receiver clock errors
4. Multipath
5. Sky Satellite position relative to receiver

The last element in the list, satellite positions relative to the receiver, is related to the satellites that a receiver is using to compute its position coordinates. Once or twice each day there is a short period of an hour or two when the only satellites whose signals the receiver can detect are in positions that do not allow for accurate coordinate determinations. The effect of this improper satellite positioning is to multiply the effects of the actual sources of error.

There are many methods to improve the GPS position accuracy. Some methods use only a GPS receiver while others use two or more receivers. An example of method based on a single GPS receiver is the averaging method. This method works averaging the latitudes and longitudes of computed GPS positions. This operation can reduce error and get better position accuracy. To reduce error by any great measure positions must be computed at frequent intervals over a period of several hours and then averaged. It is difficult to predict exactly the amount of error reduction to be expected from averaging a certain number of positions over a given time period. This method is widely used when an accurate localization of a given fixed point is required, while it is not usable in dynamic conditions.

Several methods based on two or more GPS receivers use the differential correction to improve the position accuracy. Differential correction can remove most of the effects of Selective Availability (S/A) and other ordinary sources of error in GPS computed positions. In this method a reference station broadcasts corrections on common view satellites on a regular basis to the remote GPS receiver, which provides a corrected position output. A typical application of this method is the navigation guidance. On the other hand, any interruption of DGPS (Differential GPS) service will lead to the loss of navigation guidance, which can develop into a vehicle accident, especially in the phase of precision approach and landing [2].

Starting from a large number of experimental observations and from the work in [3], in this paper the authors propose a method to improve the GPS position accuracy using a single receiver.

The remaining part of this work is organized as follows: in section II some related works are reported, section III proposes a brief problem overview while section IV describes the proposed system. In section V the results of some experiments are reported and the conclusions are in section VI.

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RELATED WORKS

Global Positioning System has had a world wide spread in the latest years, this fact has attracted the interest of many researchers that have studied many aspects of this system. In [4] authors propose an interesting overview of the today Global Navigation Systems providing an accurate description of the GPS system.

There are many research works focused on the evaluation of the GPS accuracy and some of them propose methods to improve it.

In [5] authors focus their attention on some geometric conditions such as satellite arrangement and satellites number. They shown that the accuracy provided by a GPS receiver decreases when it uses satellites having a low elevation. In [6] the authors propose a method to improve the accuracy of DGPS.

An interesting approach to DGPS accuracy improvement can be found in [7] where the author uses a recurrent wavelet neural network.

The Neural Network (NN) approach provides a promising and very realistic computational alternative. The NNs are trainable, dynamic systems that can estimate input-output functions. They have been applied to a wide variety of problems since they are model-free estimators, i.e., without a mathematical model [8]. Other interesting aspects of the neural networks are their highly parallel calculation ability, strong robustness and fault tolerance. So using the neural network for model identification is a very effective way.

PROBLEM OVERVIEW

From a theoretical point of view, a GPS receiver installed in a fixed position, should provide ever the same coordinate, but actually it is not so. Figure 1 shows a scatter of the points given by a GPS receiver installed in a fixed position for 53 hours (190800 samples). The latitude and longitude coordinate of these points are plotted respectively in figure 2 and figure 3 where the x-axis represents the time of acquisition.

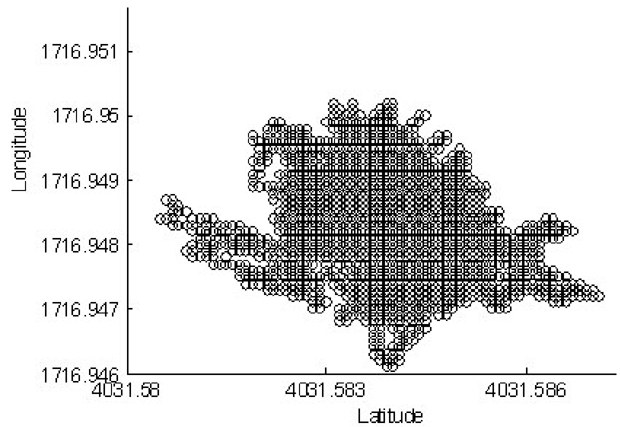

Figure 1 - a typical scatter of the points given by a GPS receiver installed in a fixed position for 53 hours (190800 samples)

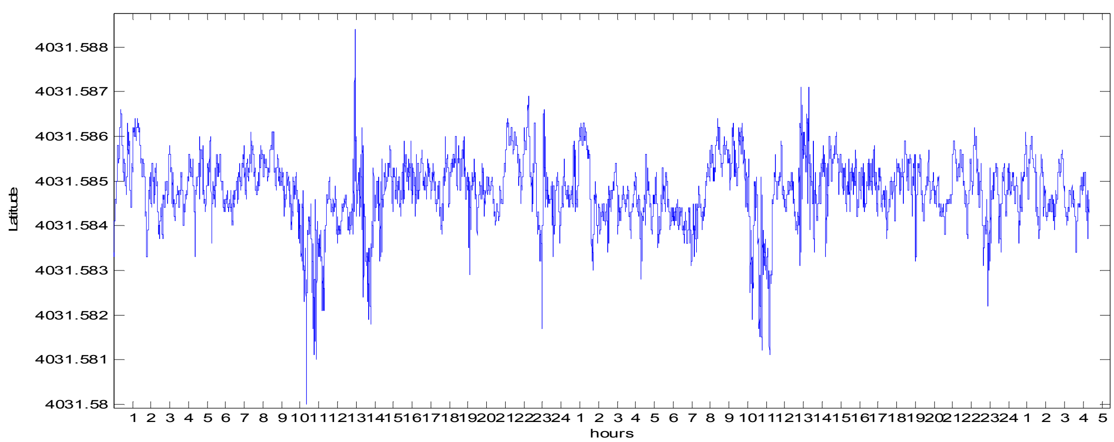

Figure 2 – Plot of the time series of the latitude

These figures point out that:

- A GPS receiver installed in a fixed position for two days gives a location varying in a range wide 2 meters. This observation derives from the conversion of the extreme coordinates shown in the scatter of figure 1 from angular measurements in meters.
- Figure 2 and figure 3 show that the location given by the receiver, varies around a mean point in a roughly periodic way.
- This periodic phenomenon could be related to the positions of satellites in sky relative to the receiver.
- The experiment set up was designed to avoid the multipath phenomena. In this way it is possible to think that the occasional variations in the time series from the periodic trends could be due to particular atmospheric conditions.

- Since the periodic trend could be due to positions of satellites in sky relative to the receiver, it is possible to define a correction method having a validity in the neighborhood of the receiver. From this point of view this method could be seen as a local GPS accuracy improving method.

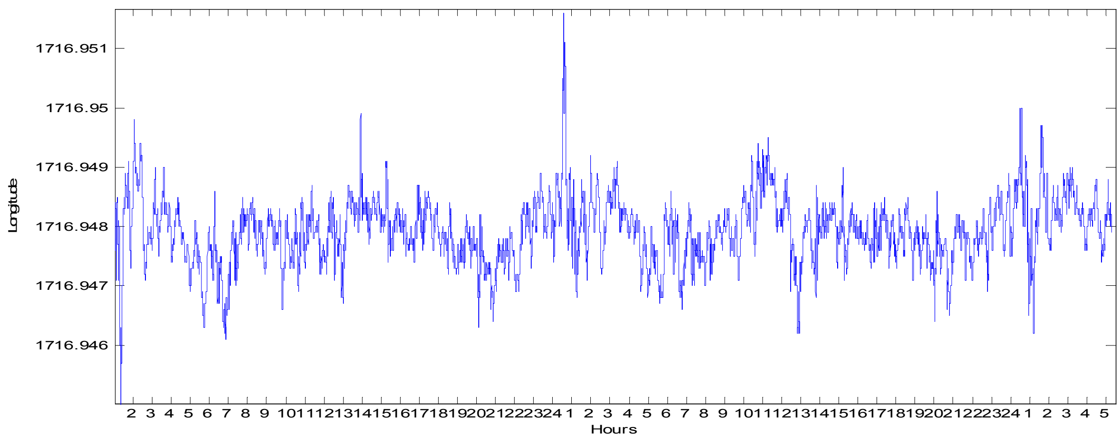

Figure 3 - Plot of the time series of the longitude.

PROPOSED SYSTEM

This work proposes a system to improve the position accuracy of a GPS receiver starting from the previous observations. Since the errors in GPS location follow a roughly periodic trend it is possible to improve the position accuracy having an analytical description of the time series shown in figure 2 and figure 3.

The periodicity of this signal was estimated using the well know method of the periodogram. As figure 4 shows, there is a strong periodic component having a 24 hours period.

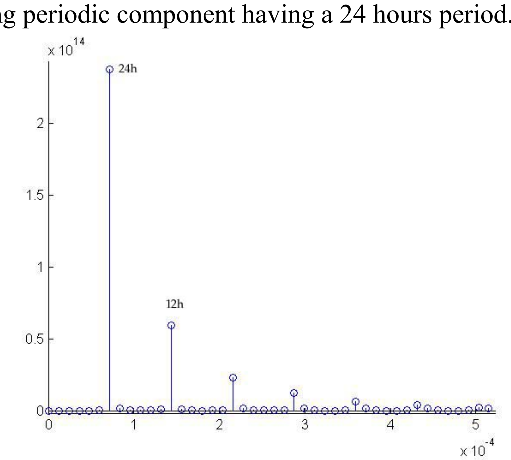

Figure 4 – The periodogram obtained analyzing the data of figure 2

The problem of determining the analytical description for a set of data arises in numerous scientific fields and applications, and can be referred to as data modelling or system identification. Neural networks are a convenient means of representation because they are universal approximators that can learn data by example [9] or reinforcement [10], either in batch or sequential mode.

With a neural network, the intense computation takes place during the training process. Once the network is trained, operation consists of propagating the data through the network. Since the computation involved during this operation consists of vector-matrix multiplication, unknown samples can be rapidly identified in the field.

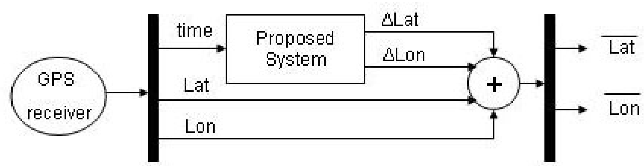

Figure 5 - A logical schema pf the proposed system

The authors propose to use a neural network to obtain the analytical description of the time series shown in figure 2 and figure 3. Once that the neural network finishes its training phase, it can be used in real time dynamic correction of the GPS position given by the receiver. Indeed, as shown above, in a given point, there is a periodic component of positioning error due to the positions of satellites in sky relative to the receiver and the magnitude of this error is a function of the time. Figure 5 shows a logical schema of the proposed system. The system acquires the UTC time from the GPS receiver and uses the neural network to find the corrections (ΔLat and ΔLon in figure 5) for latitude and longitude coordinates (Lat and Lon in figure 5) measured by the receiver. ΔLat and ΔLon are then added to Lat and Lon to obtain the corrected measures of latitude and longitude ($\overline{Lat}$ and $\overline{Lon}$ in figure 5).

The system is trained to learn 24 hours of the time series shown in the previous figures.

In this work a generalized regression neural networks was used because they are a kind of radial basis network that is often used for function approximation. In this work a two-layer network has been used. The first layer has neurons with a radial basis transfer function while the second layer uses neurons with linear transfer function.

EXPERIMENTS

In this work a large set of experiments was carried out using the following set-up: a GPS receiver was installed in a fixed point and connected to a PC that continuously acquired the position.

The usb GPS receiver BU-353 was used in these experiments. Its main characteristics are:

- Chipset SIRF Star III
- 20 channels all-in-view tracking
- sensitivity -159 dBm
- GPS protocol: NMEA 0183
- Average acquisition rate: 1 second.

The acquisition of GPS receiver position lasted 20 days using a sample rate of 1 Hz. The so obtained time series was divided in 20 blocks of 24 hours each one. The neural network was trained using one of the twenty blocks selected in a random way (24 hours of acquisition). The remaining 19 blocks were used as test set. The performance of the proposed system was evaluated in terms of round mean absolute error of the time series using the following formula:

$$MAE = \frac{\sum_{i=1}^{N} | f_i - y_i |}{N}$$

where N is the number of samples, f_i is the prediction and y_i the true value. In this work y_i is the mean value of the time series.

This experiment was repeated 5 times using different blocks as training set and the remaining blocks as test set. The proposed correction method introduces a mean improvement in the accuracy of 25%. This value was computed as mean of the five experiments previously described. Figure 6 and figure 7 show an example of GPS coordinate correction obtained using the proposed system. Figure 6 refers to the longitude component while figure 7 refers to latitude component. In both the figures the bold line is the signal obtained using the proposed method, the normal line is the signal acquired from the GPS receiver while the horizontal line is the correct value. In these figures all the values were normalized to 0, i.e. the mean value of the time series (as explained above it is considered the real position value) was subtracted to each sample.

The same experiments described above were carried out using an autoregressive model in order to compare the performance of the proposed method with a classic one. A set of experiments were carried out to identify the model. In order to define the correct order of the autoregressive model an evaluation of the final prediction error was carried out as shown in figure 9. The selected order was 7 because it seems to be a good compromise between performance and complexity of the model. As figure 8 shows, the autoregressive model introduce a correction to the GPS signal smaller than that introduced by the proposed neural network. The average improvement in the accuracy of the GPS position measure, obtained using the autoregressive model, was 17%.

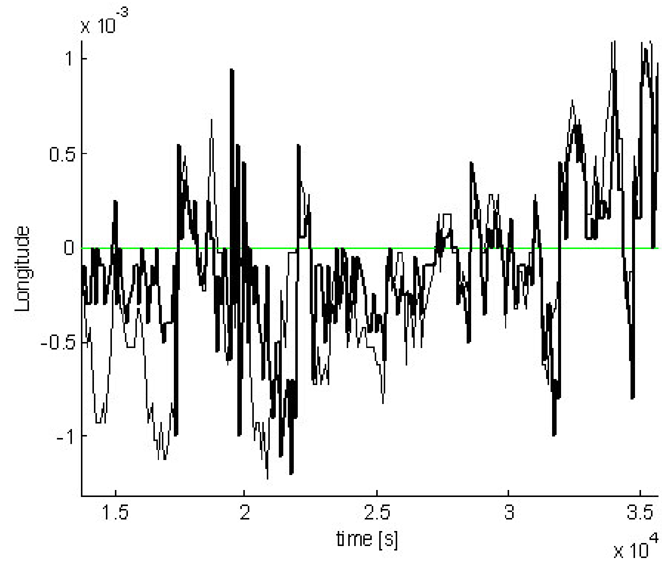

Figure 6 - an example of longitude correction. The bold line is the signal obtained using the proposed method, the thinner line is the signal acquired from the GPS receiver while the horizontal line is the correct value (normalized to 0)

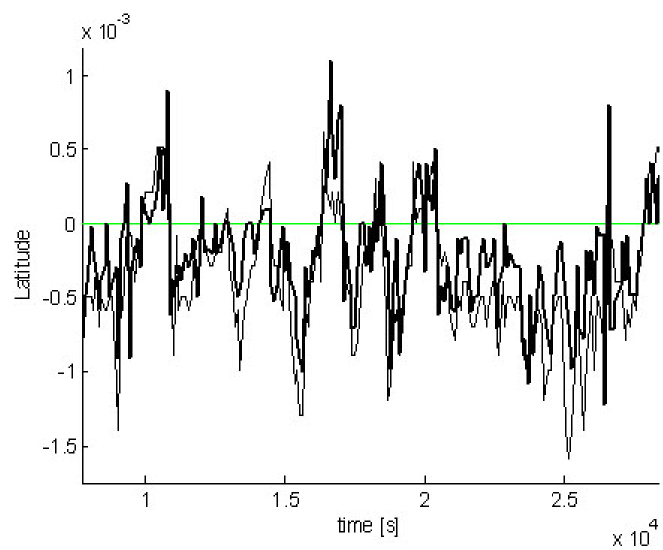

Figure 7 - an example of latitude correction. The bold line is the signal obtained using the proposed method, the thinner line is the signal acquired from the GPS receiver while the horizontal line is the correct value (normalized to 0)

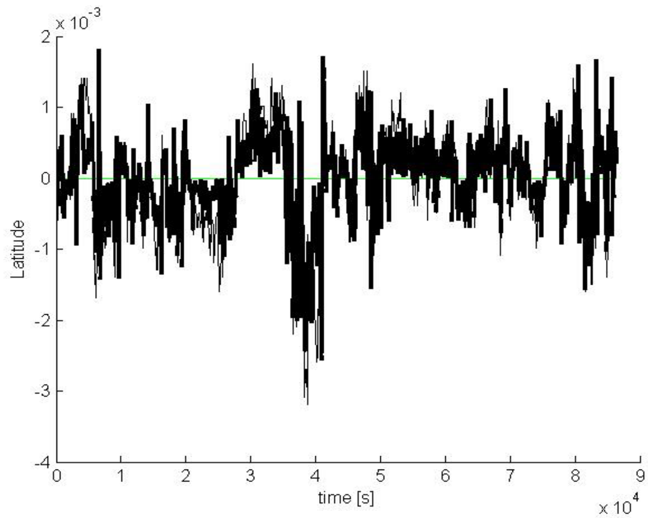

Figure 8 - an example of latitude correction obtained using an AR model. The bold line is the signal obtained using the AR model, the thinner line is the signal acquired from the GPS receiver while the horizontal line is the correct value (normalized to 0). It should be noticed that the two signals are very similar. This happens because the AR method introduces a small correction to the GPS signal.

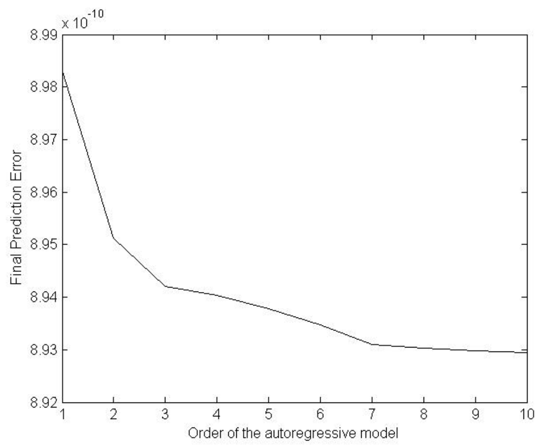

Figure 9 - Final prediction error as function of the autoregressive model's order

CONCLUSIONS

In this work the authors propose a method to improve the GPS position accuracy using only a GPS receiver. This method is based on a generalized regression neural networks because this is a kind of radial basis network that is often used for function approximation. In this work a two-layer network has been used.

This neural network is used to learn the periodic components of GPS positioning error in order to remove them from the GPS signal as a systematic error that is function of the time. These periodic components could be related to the positions of satellites in sky relative to the receiver.

Neural networks can provide several advantages over conventional regression models. They are claimed to possess the property to learn from a set of data without the need for a full specification of the decision model; they are believed to automatically provide any needed data transformations. They are also claimed to be able to see through noise and distortion.

As the experimental observations show, this correction method can be used only in a certain neighborhood of the point where the data used to train the neural network have been acquired. The dimension of this neighborhood depends on the orography of the region where the system has been trained. Future works will aim to investigate on the dimension of these neighborhoods.

The results of the experiments show that the proposed system introduces a mean improvement in the accuracy of the GPS position measure of 25%. The proposed method was compared with an autoregressive model and, as the proposed experiments show, the former outperform the latter.

It should be highlighted that this correction method is applicable also in dynamic conditions (i.e. when the GPS receiver is moving). Indeed, as the proposed experiments show, the periodic error component under analysis is a function only of the time in which the signal is sampled and of the region where the receiver is positioned (that should be the same in which the system was trained).

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