AIDING GPS WITH NEURAL NETWORK CALIBRATED LORAN-C

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SUMMARY

Loran-C is a land-based navigation system with a high repeatable accuracy. However, precise positioning requires the distortions of Loran-C signal propagation to be compensated carefully. This paper shows, how neural networks can be used to learn the signal distortions by GPS data. A simulation shows that this approach can reach nearly the same positioning quality than GPS. Therefore, neural network calibrated Loran-C can effectively aid GPS in cases when GPS availability is weak.

1 INTRODUCTION

Loran-C is a land-based navigation system with a high repeatable accuracy. Therefore, Loran-C can effectively aid GPS in cases when GPS availability is weak. In [1] it has been shown that integrated GPS/Loran-C increases availability in some mountainous areas considerably.

However, precise Loran-C based positioning requires the distortions of Loran-C signal propagation to be compensated carefully [2], [3]. This paper shows, how neural networks can be used to learn the signal distortions by GPS data. A simulation shows that this approach can reach nearly the same positioning quality than GPS.

2 LORAN-C OVERVIEW

Loran-C is a low frequency land-based radio navigation system. Conventionally, a Loran-C user receiver measures the time difference (TD) between the arrival of a pulse from the master transmitter and a secondary transmitter of a particular chain. A Loran chain consists of one master transmitter and between 2 and 4 secondary transmitters. The transmitter locations are well-known and the propagation speed of the Loran pulse can be estimated. Each measured TD defines a hyperbolic line of position. Two TDs are necessary to obtain the user position in two dimensions. If more than two TDs are available a least square solution can be used. Loran-C is not able to provide accurate estimates of the user altitude.

The largest source of error in Loran-C positioning is variation in the signal propagation velocity. Since Loran-C signals mainly travel by groundwave propagation, the propagation speed of the signals is effected by different ground conductivities (caused by varying terrain like water or land terrain). The total travel time of the Loran-C signals is modeled as:

$$T = T_{PF} + T_{SF} + T_{ASF}$$

T_{PF} (Primary Factor) is the ideal travel time through atmosphere. T_{SF} (Secondary Factor) is the additional travel time need to travel over an all-seawater path. T_{ASF} (Additional Secondary Factor) is the additional time for travelling over terrain of various conductivities. In contrast to PF and SF, ASF is very difficult to model [3]. Neglecting ASF can cause positioning errors of several hundred meters [4]. Usually, ASF is measured explicitly as correction values for TDs in the area of interest and is collected in ASF correction tables. This has been done e.g. for the US coastal region (Fig. 1). Because of the unmodeled time-dependant ASF variations and the spacing of the table there still are errors in positioning accuracy of about 200m drms [4].

Errors due to ASF are mainly biased errors. Moreover, there are also some noise errors which come from synchronization errors in secondaries and user measurements. These errors may be up to 150 nsec depending on the user receiver quality [5].

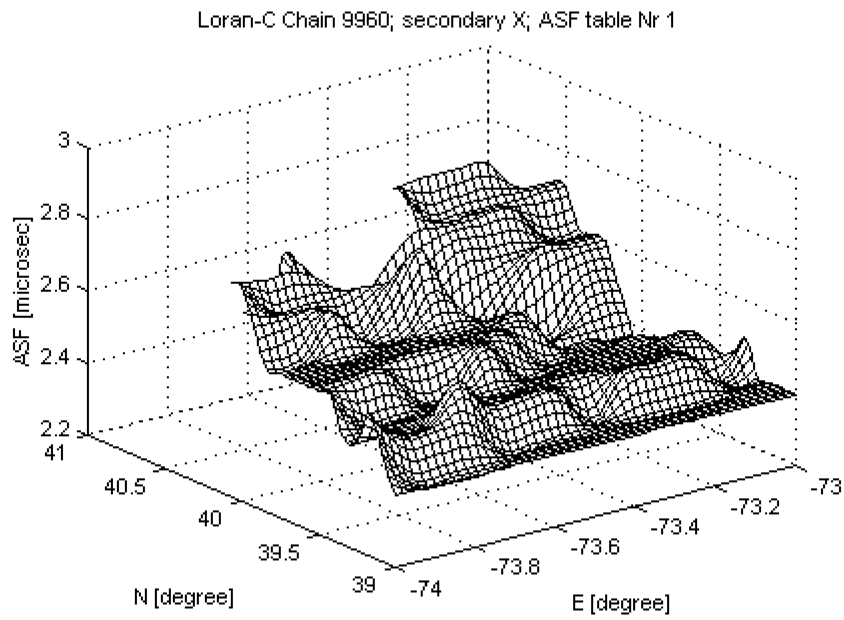

Fig. 1: ASF correction table for the sea area at the coast of Long Island, New York, for the secondary 9960-X. At each geodetic coordinate in the area a TD correction value can be looked up.

3 LEARNING ASF WITH NEURAL NETWORKS

Neural networks [6] are composed of simple elements (neurons) which are highly connected and are operating in parallel. Neural networks are able to approximate arbitrary input/output functions. The function computed by a neural network is mainly determined by the connection weights between the neurons. Neural networks are usually trained, so that inputs lead to specific target outputs. Training is performed by adjusting the weights of the connections between the neurons, so that an overall error sum is minimized.

The most popular neural network model are the feed-forward networks, which have also been used in our approach. They consist of several layers of neurons: input layer, at least one hidden layer and one output layer. All neurons between two neighbour layers are completely connected.

The idea of our training procedure is shown in Fig. 2. From the TD measurements of a Loran Receiver a user position $(lat,lon)_{Loran}$ is calculated. Note, that for each secondary of the considered Loran chain a TD value is measured. Since the TDs are not corrected for ASF, the position might be less precise. The error of the Loran-TD measurements can be estimated from the GPS-based position fixes:

$$\Delta TD = TD_{Loran} - TD_{GPS}.$$

The position $(lat,lon)_{Loran}$ is feed to a 3-layered neural network with 16 neurons in the hidden layer. The TD error ΔTD is taken as the target output for the neural network. After training, the neural nets can be used for correcting TD measurements.

Note, that each secondary has its own neural network for correcting its TD value.

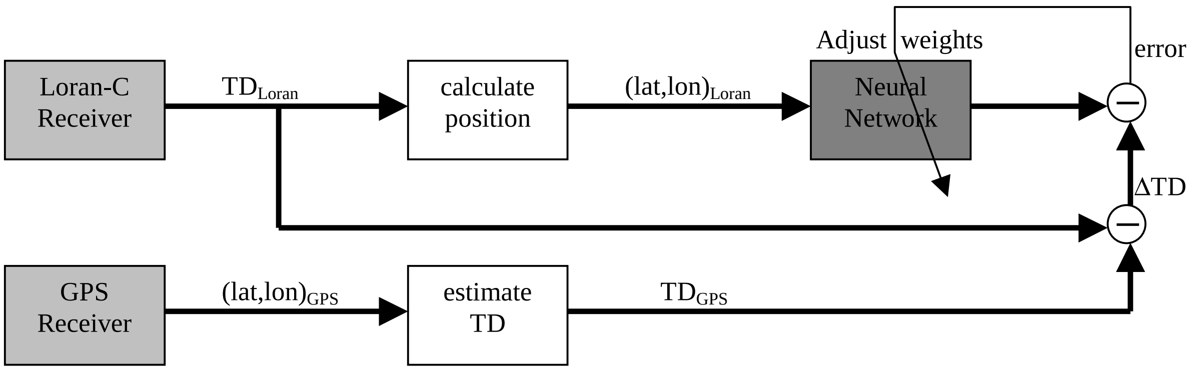

Fig. 2: Neural network training procedure. Actually, TD_{Loran}, TD_{GPS} and ΔTD are vectors with values for each secondary. Also, there is a neural network for each secondary.

4 SIMULATION RESULTS

The Matlab Toolbox Satnav [7] has been used for simulating GPS signals without SA but with all atmospheric error sources. Moreover, we have developed a Loran Navigation Toolbox. One of the Toolbox function generates TDs with signal propagation error due to ASF. The ASF tables from [4] have been used for that. Also, TD noise can be added.

First, a path with about 250 true user positions has been generated (see Fig. 3). Then, GPS based position fixes $(lat,lon)_{GPS}$ and TD values for each secondary with ASF and TD noise (normally distributed with $\mu = 0$) has been generated. Remember, that the TD noise is caused by synchronization errors in the secondaries and user measurements. From these generated data Loran based positions $(lat,lon)_{Loran}$ and the estimated TD errors ΔTD are computed. The simulated time interval is about 4 hours. In that time a mean number of 7.12 satellites have been available for GPS position fixes. The mean PDOP has been 2.01.

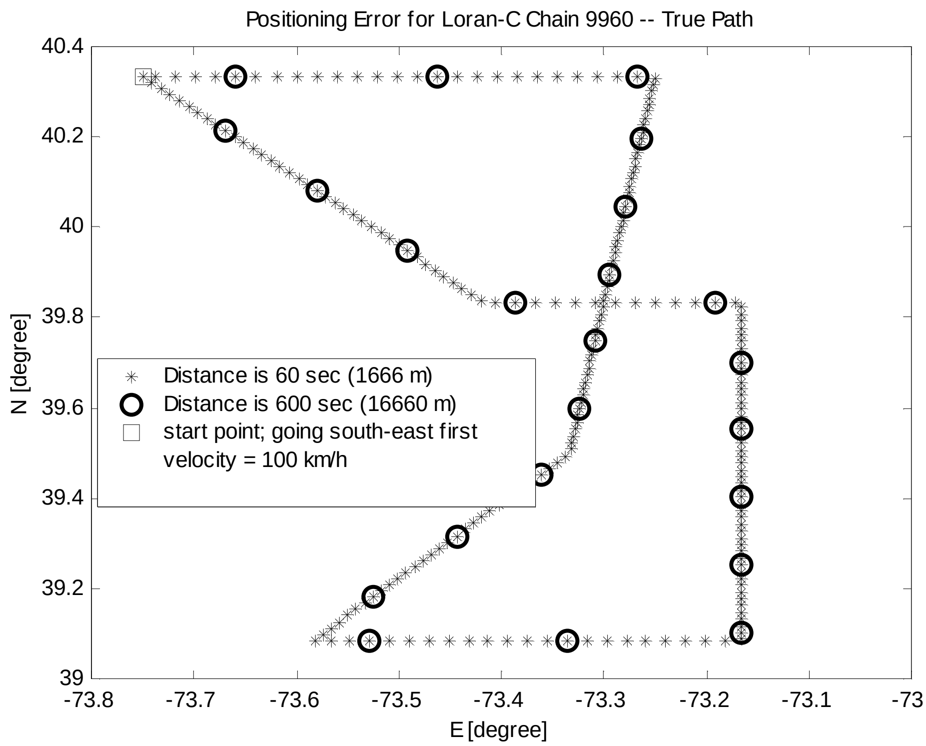

Fig. 3: Path with about 250 user positions

Then, the data have been used to train the neural networks. Finally, the trained neural networks have been tested for the same path but with newly generated TD values (i.e. newly generated TD noise). It has the same effect as driving the path once again and testing the neural network calibrated Loran-C.

We have made several train and test runs through the path with different TD noise levels (i.e. different standard deviations σ). Table 1 summarizes the horizontal position errors for GPS, uncalibrated Loran-C and neural network calibrated Loran-C. Loran-C positioning error is mainly caused by ASF and is biased. TD noise has only a small influence. In the neural net calibrated Loran-C positioning the ASF effect is almost eliminated. The error is mainly contributed by TD noise.

Table 1: Horizontal position error drms [m] for GPS, Loran-C and neural network calibrated Loran-C. The quality of Loran-C (with and without neural networks) depends on TD noise.

TD noise σ [nsec]	GPS	Loran-C	Neural net calibrated Loran-C
0	4.71	403.75	4.51
50	4.71	404.18	14.63
100	4.71	404.34	27.79
150	4.71	405.98	42.52

Fig. 4 shows details of positioning errors of GPS and Loran-C (without ASF correction) for σ_{TD} = 0 nsec. Fig. 5 compares positioning errors of GPS with neural network calibrated Loran-C. The positioning is of the same quality than GPS.

Remember, that GPS was highly available in the generated path (mean PDOP = 2.01). In cases of weak GPS availability (e.g. urban or forest terrain), neural network calibrated Loran-C can effectively be used to aid GPS.

Finally, Fig. 6 compares the “true” ASF (modeled in the Toolbox) with GPS and the neural network estimate. The neural network has a slight smoothing effect.

5 CONCLUSIONS AND FUTURE WORKS

Loran-C can be used to aid GPS in cases of weak availability. However, Loran-C positioning quality is only precise enough if accurate ASF modeling is included. We have employed neural networks to learn the TD errors due to ASF by GPS data. The simulation results are very promising.

In a next step our approach will be implemented in a real Loran-C receiver. Two extensions seem to be interesting:

- In [8] a similar approach has been presented. The authors suggest to improve the neural network based calibration by increasing the number of input neurons. Parameters like signal-to-noise ratio, field strength, etc. could be useful to incorporate the reliability of the navigation data.
- Another very important point is to investigate the ability of neural networks to be adapted online due to ASF variations and to be extended with completely new ASF knowledge of new areas.

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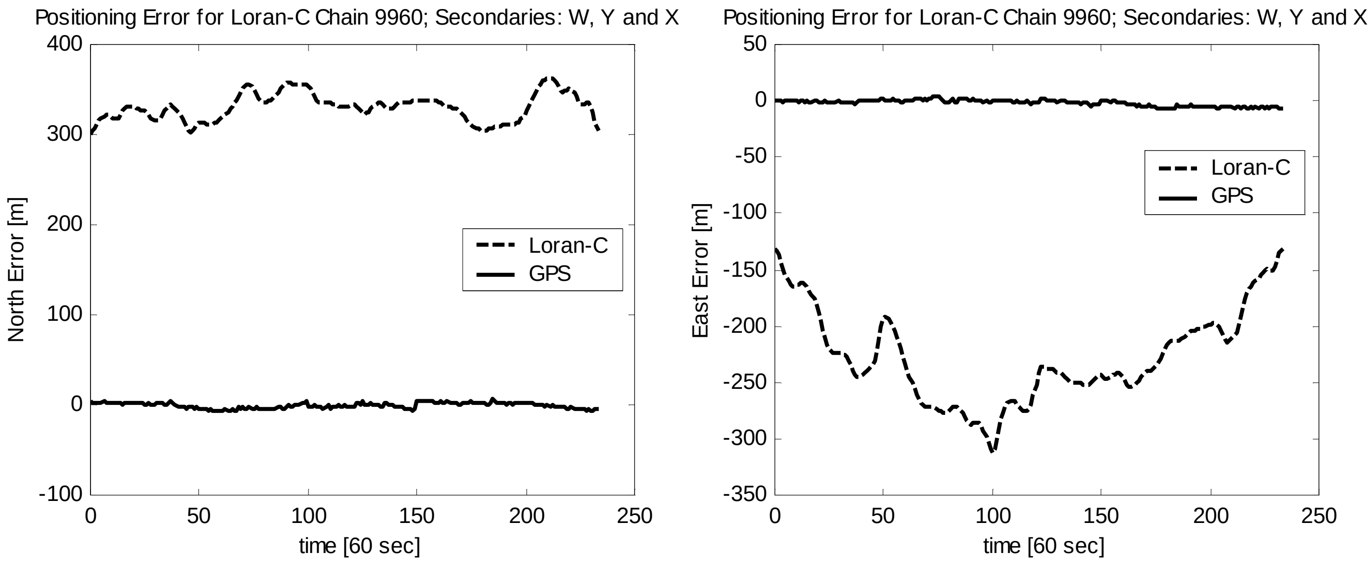

Fig. 4: Positioning error of Loran-C and GPS (σ_{TD} = 0). Loran-C positioning is without correcting for ASF.

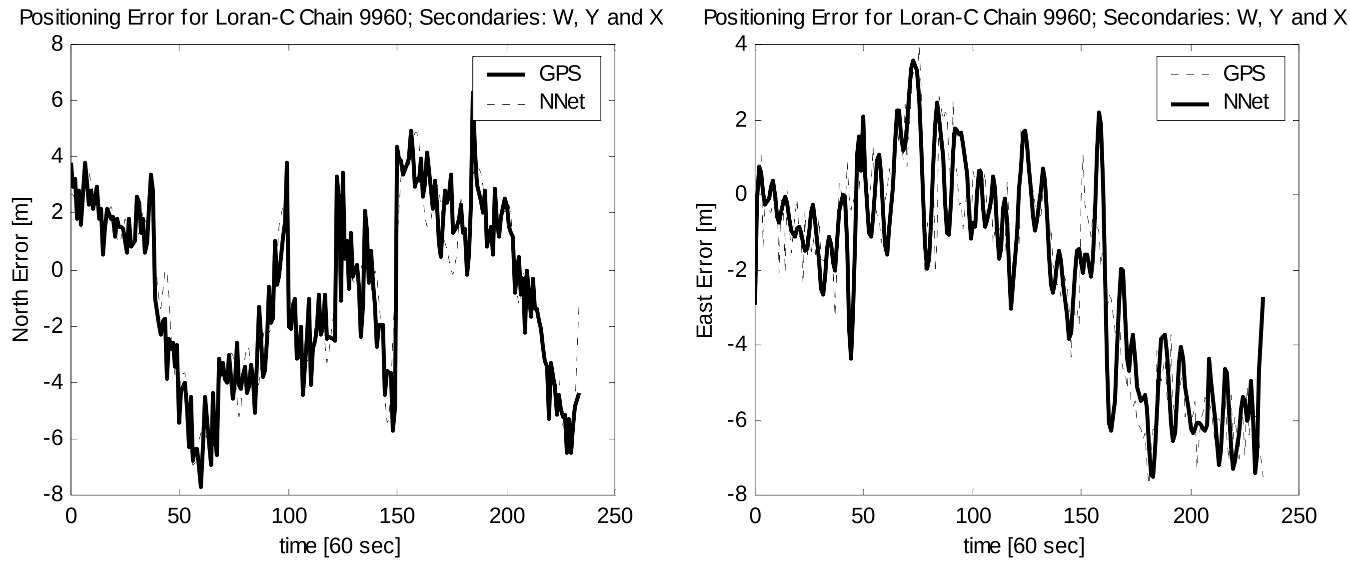

Fig. 5: Positioning error of GPS and neural network calibrated Loran-C (σ_{TD} = 0).

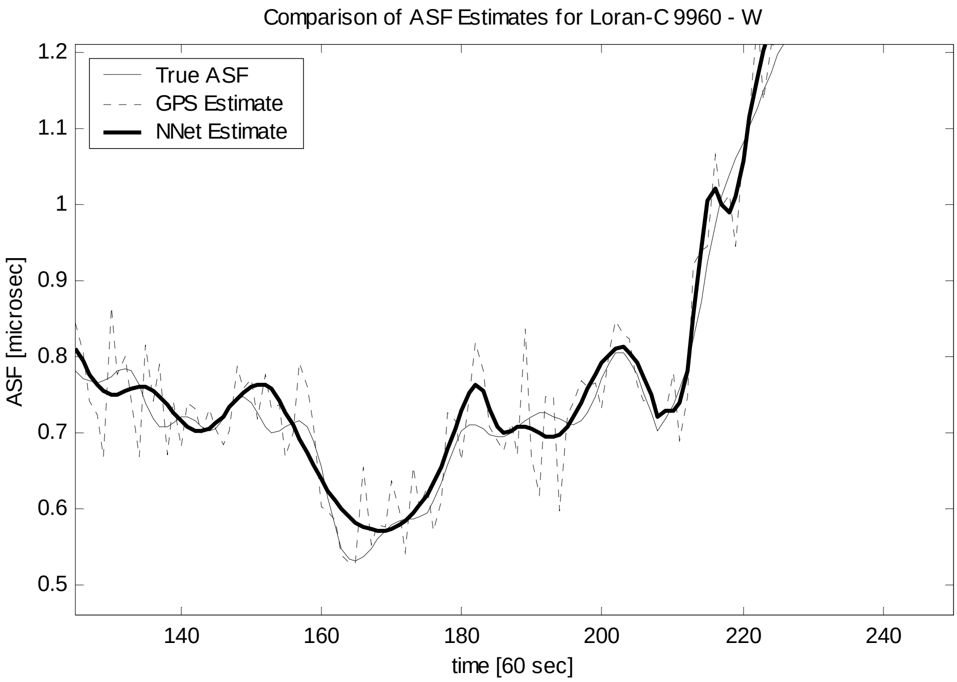

Fig. 6: Comparison of “true” ASF (modelled in the Loran Toolbox) and GPS and neural network estimate of ASF. The neural network based estimate is a smooth approximation of the “true” ASF.