# IMPROVING GPS ACCURACY USING NEURO-FUZZY SYSTEM

**Samer I. Akoum, Yousef Al-Assaf**

*School of Engineering, American University of Sharjah*
*bioeng@emirates.net.ae; yassaf@ausharjah.edu*

Abstract: Single Global Positioning System (GPS) receiver is capable of horizontal accuracy within 10 to 20 meters. Further improvement in accuracy employs more sophisticated and costly equipment. However, many engineering applications that require GPS data may not require fine accuracies and hence the use of expensive equipment may not be justified. In this research, neuro-fuzzy system will be considered to improve the accuracy of GPS receiver by utilizing various GPS parameters such as position dilution of precision (PDOP) and signal to noise ratio (SNR). Significant improvement in GPS accuracy is achieved using the proposed method. 

Keywords: global positioning systems, fuzzy logic, artificial intelligence, neural network, position error.

## 1. INTRODUCTION

The GPS is a satellite-based navigation system that has replaced preceding positioning systems (Ghalehnoee, et al., 2002). Essentially, as GPS satellites circle the earth, they send information to GPS receivers on earth surface leading to determination of time, latitude, longitude and altitude (Zarchan, 1997).

The accuracy of GPS positioning depends on several factors: the earth atmosphere, signal multipath, receiver clock accuracy, satellites availability and satellites constellation (Zarchan, 1997). Stand-alone GPS receiver can reach as well as 10m accuracy (Kennedy, 2002).

Different techniques are used to overcome these factors in order to achieve better accuracy. These include: Differential GPS (DGPS) and Real Time Kinematics (RTK). Such techniques provide sub-meter and sub-centimetre accuracy respectively (Zarchan, 1997; Trimble, 1995).

Nevertheless, such techniques have limitations: cost, range from the base station, signal integrity, loss of RTCM message, multipath and receiver architecture (Leick, 1995).

Artificial intelligence techniques have been used to improve the position accuracy of a stand-alone GPS receiver. (Lin, et al., 1996) had used fuzzy logic technique to improve GPS positioning accuracy utilizing PDOP and SNR parameters. Similar work was conducted by (Ghalehnoee, et al., 2002) to improve determining the location of a moving vehicle on a map by low cost GPS receiver. The PDOP and SNR were also used in this work.

Recurrent neural network was used to predict the corrections needed for a stand-alone GPS receiver (Sang, *et al*., 1997). Numerical examples showed that the prediction accuracy was better than 1 m for 10 s prediction and 1.3 m for 30 s prediction.

In this paper, a neuro-Fuzzy system is developed to improve the GPS positioning accuracy. The method employs the PDOP, SNR and Elevation (ELEV) parameters as inputs to the algorithm.

## 2. THE NEURO-FUZZY SYSTEM

The neuro-fuzzy methodology used in this work is shown in Fig. 1. The factors that reflect the accuracy of the fix (Latitude/Longitude reading from GPS receiver) include: PDOP, SNR and elevation (ELEV).

PDOP is a factor that reflects the effect of the satellites' constellation on the accuracy of the fix position, the smaller the factor is, the better is the accuracy of the fix position (Trimble, 1995).

ELEV is the elevation of the tracked satellite that also reflects how good the fix is. It is the angle from the horizon to the observed position of the satellite. The higher the value, the more accurate the fix position is (Trimble, 1995).

SNR is a measurement of the satellite signal strength; it indicates how good the tracked satellite signal is. The higher the value, the more accurate the fix position is (Trimble, 1995).

For 2D positioning, a constellation of at least three satellites is needed.

Fig. 1 indicates that, for each fix, the ELEV vector of the tracked satellites is used to obtain an RF-SNR value (reliable factor for SNR) for each tracked satellite. The SNR values are then scaled according to the corresponding RF-SNR value and then the sum of the scaled SNR values (SSNR) is obtained for that fix. Both SSNR and PDOP are then processed to obtain the output fuzzy variable RF (reliable factor) which is a scale from 0 to 1; a high value will indicate a good fix position obtained by the GPS receiver.The membership functions are shown in Fig. 2. Table 1 and Table 2 show the rules for the first and the second fuzzy stages respectively.

The RF value obtained from the fuzzy logic process is used as the input for a neural network. The neural network employed is a feedforward 1-5-2 multilayer perceptron network that uses the backpropagation learning rule, the hyperbolic tangent sigmoid function is the transfer function used all over the network. The two output neural variables are the difference in latitude and the difference in longitude of the obtained position fix respectively from the actual position.

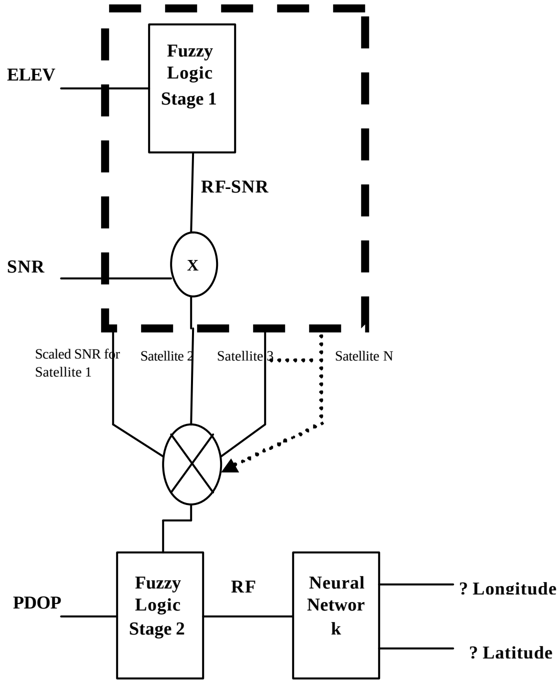


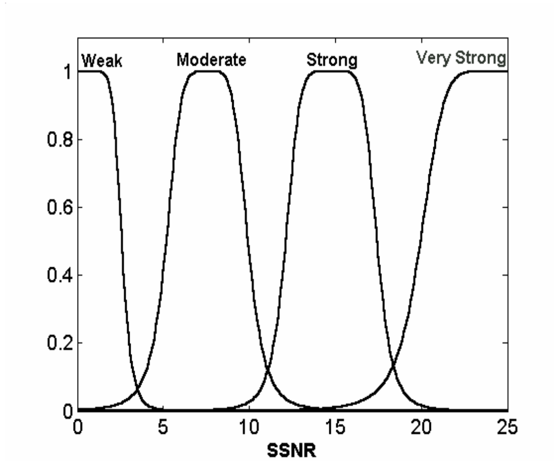

Fig. 1. The neuro-fuzzy system methodology.

Table 1: Rules for the first fuzzy set.

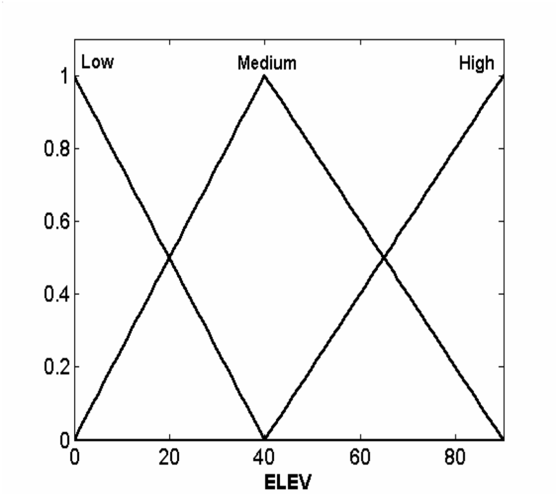
| ELEV | RF-SNR |
|---|---|
| Low | Low |
| Medium | Medium |
| High | High |

Table 2: Rules for the second fuzzy set.

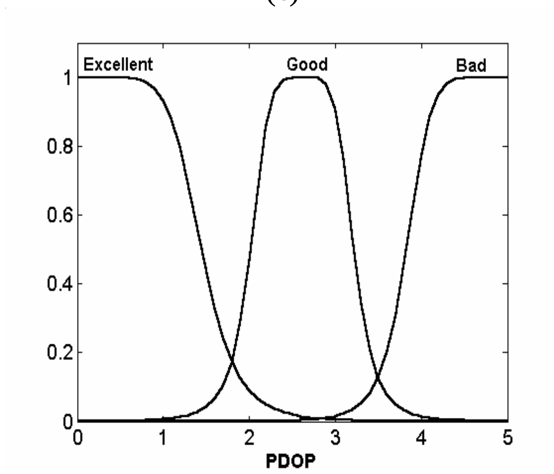
| SSNR \ PDOP | Bad | Good | Excellent |
|---|---|---|---|
| Weak | Small | Small | Small |
| Moderate | Small | Small | Medium |
| Strong | Small | Medium | Large |
| Very Strong | Medium | Large | Very Large |



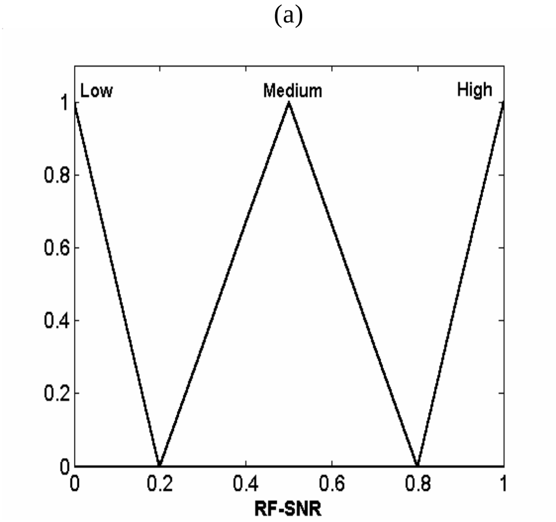

(c)



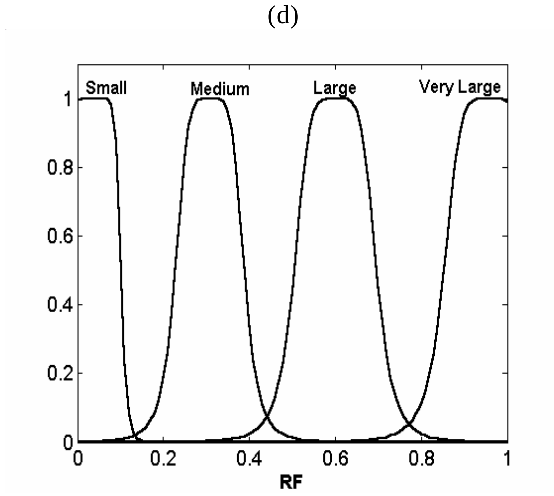

(a)




(d)




(b)




(e)

Fig. 2. The membership function for:
a. ELEV, b. RF-SNR, c. SSNR, d. PDOP, e. RF.

## 3. SYSTEM SETUP

Trimble 4000RS GPS receiver is used to collect position fixes (latitude / longitude) as well as the previously mentioned factors per second (fix rate). This is done by capturing NMEA-0183 messages from the GPS receiver serial port from which the latitude/longitude and the factors: PDOP, ELEV and SNR can be extracted and used.

The receiver is stationed on a known location to act as the system (base station). Data is logged for 16 hours after which they are fuzzy processed to be used to train the neural network.

The receiver is then stationed at several known locations (remote stations) logging the data for up to 2 hours. Then, the data is used to test the trained neural network after being fuzzy processed.

## 4. EXPERIMENTAL RESULTS

Fig. 3 shows the 16 hour-fixes collected at the base station. The fixes are plotted relative to the actual position where the coordinates (0,0) represent accurate positioning. After fuzzy processing, the RF values obtained are compared with a threshold value; if the RF value is greater than the threshold value, then the fix is considered as good. Fig. 4 shows that a threshold value greater than 0.4 will lead to a decrease in the latitude/longitude deviation. In this work, fixes with RF values greater than 0.4 are adopted for further processing, although higher threshold value will lead to more decrease in the deviation, but this will reduce the number of fixes to be adopted; around 25,000 adopted fixes are obtained.

Fig. 5 shows the fixes that meet this criterion. These chosen fixes are then used to train the neural network. Fig. 6 shows the training parameter for the neural network.

To test the neural network accuracy, GPS data is collected from three remote stations. The three stations (A, B and C) are at a distance of 400m, 200m and 4.4 km from the base station respectively. The time of data collections is 2 hours, ½ hour and 2 hours for stations A, B and C respectively. Fixes with RF values greater or equal to 0.4 are chosen for processing. The results of the neuro-fuzzy system are shown in Fig. 7, Fig. 8 and Fig. 9.

Table 3 shows a summary of the accuracies obtained at the three stations. In the table, the $E_b$ is the distance between the average of fixes as measured by the GPS receiver and the actual position. However, $E_f$ is the distance between the neural network corrected fixes and the actual position. As it can be deduced, the neuro-fuzzy system has -in average- improved the GPS positioning by 50%-70%.

Table 4 shows that decreasing the fix rate has no significant effect on the accuracy of the neuro-fuzzy system. Consequently, when carrying out static survey, logging the data at a fix rate of 1 minute is acceptable and this reduces the computational requirement.

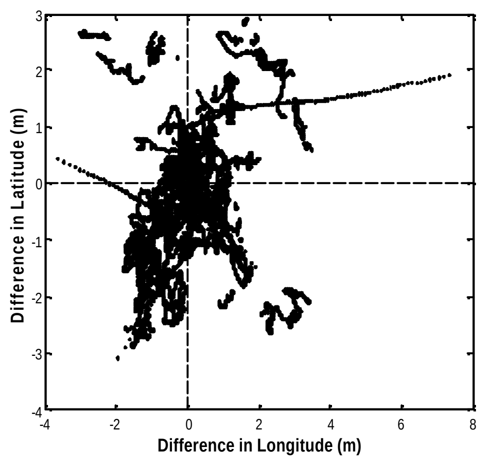



Fig. 3. Fixes obtained at the base.

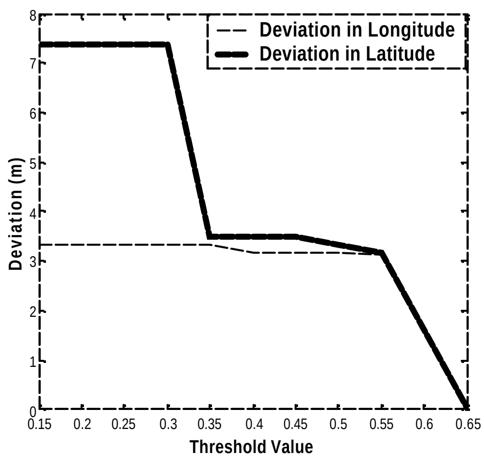



Fig. 4. Threshold value vs. deviation, which is obtained by adopting fixes greater than the threshold value.

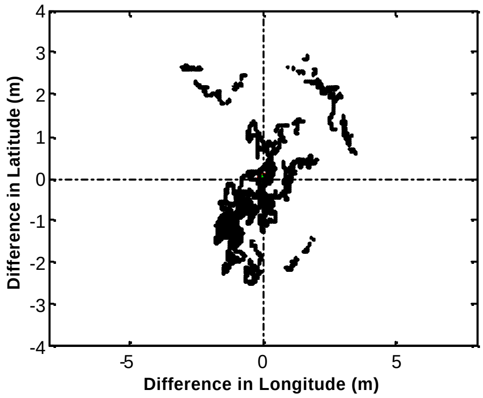



Fig. 5. Fixes obtained at the base with RF >= 0.4.

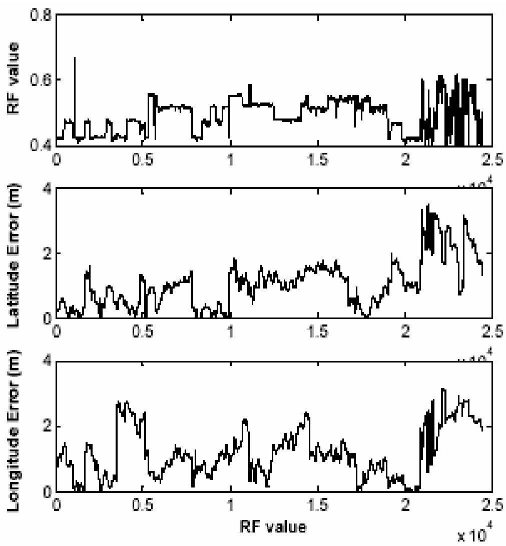



Fig. 6. Training parameters for the neural network.

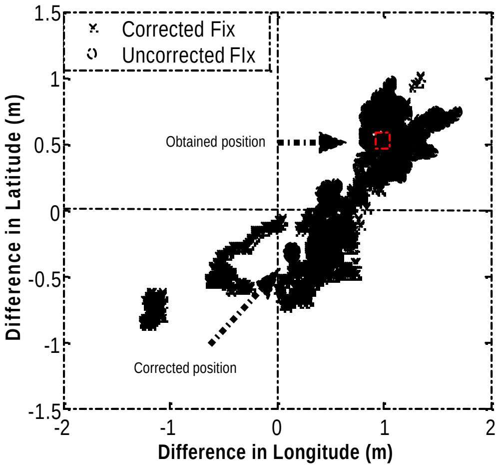



Fig. 7. Result of the neuro-fuzzy algorithm for station A

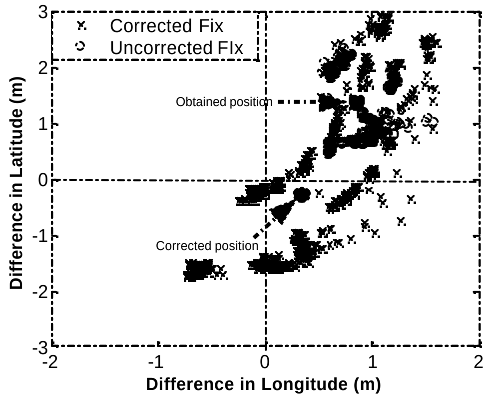



Fig. 8. Result of the neuro-fuzzy algorithm for station B.

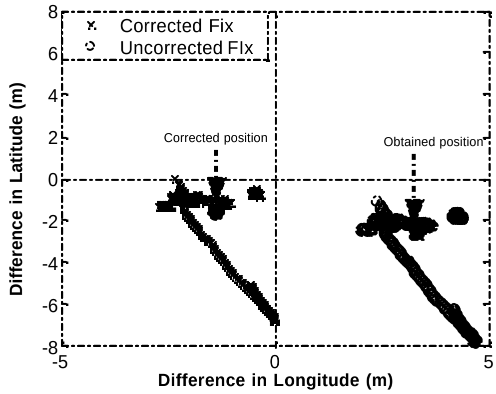



Fig. 9. Result of the neuro-fuzzy algorithm for station C

Table 3: Errors obtained with and without using the neuro-fuzzy system.

| | $E_b$ (m) | $E_f$ (m) |
|---|---|---|
| Station A | 1.1225 | 0.3508 |
| Station B | 1.5988 | 0.4482 |
| Station C | 4.2703 | 2.0862 |

Table 4: Errors obtained with and without using neuro-fuzzy system for different fix rates.

| | Fix rate (sec) | $E_b$ (m) | $E_f$ (m) |
|---|---|---|---|
| Station A | 10 | 1.1225 | 0.3471 |
| | 30 | 1.1104 | 0.3427 |
| | 60 | 1.1104 | 0.3276 |
| Station B | 10 | 1.6128 | 0.4996 |
| | 30 | 1.6184 | 0.5154 |
| | 60 | 1.5741 | 0.5004 |
| Station C | 10 | 4.3133 | 2.0579 |
| | 30 | 4.3226 | 1.9490 |
| | 60 | 4.3091 | 1.9516 |

In dynamic survey, the need of corrected position fix at a rate from 10 s to 30 s is a must. In order to check the performance of the developed neuro-fuzzy system on dynamic positioning, for each specified period of recording ($W_z$) the average of the fixes is computed and processed through the developed neuro-fuzzy system. For example: every 1 minute, data is collected and an average fix is obtained with and without neuro-fuzzy corrections. Fig.10 shows typical results for $E_b$ and $E_f$ obtained from station A for different values of $W_z$. As it can be seen, the neuro-fuzzy algorithm is able to make good corrections that lead to better fix estimation for most of the recording time. However, the correction is not uniform during the recording. For example, the $E_f$ at certain few times was larger than $E_f$. One justification for this could be that the RF value is not reflecting the proper error due to the fact that no perfect precision can be obtained as an output from fuzzy logic.

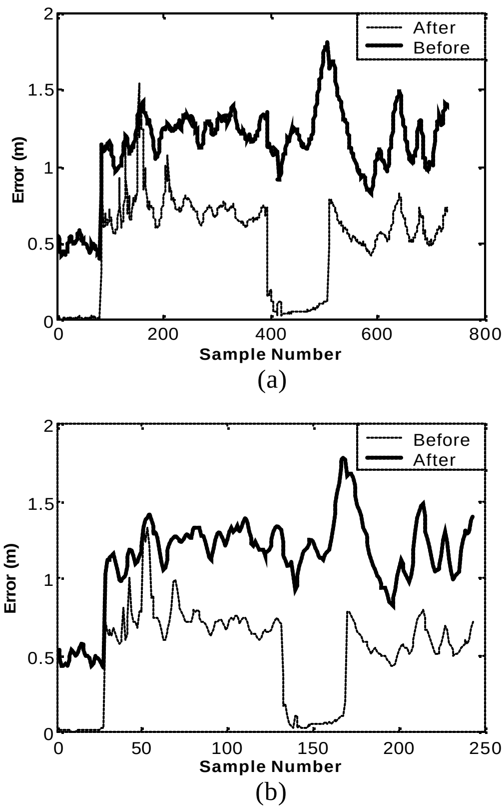



Fig. 10. Error obtained by changing the number of samples at station A . Number of samples = 10(a), 30(b).

Eliminating the fixes with very high PDOP values or very low SNR values, i.e. not including them as input for the neuro-fuzzy system, would further improve the positioning accuracy. Alternatively, logging more data at the base station (24 hours instead of 16 hours) could improve the performance of the neural process, as more training data will be available.

## 5. CONCLUSION

In this paper, a neuro-fuzzy algorithm is developed and tested to improve the GPS positioning accuracy. GPS parameters including PDOP, SNR and ELEV are used as input to the algorithm. The algorithm is trained on the data obtained from one base station and tested at other remote stations. Results have shown that a significant improvement in GPS fix accuracy can be achieved. It is also shown that decreasing the fix rate does not cause any significant effect on the performance of the system. However, for dynamic survey, conditional constraints are to be used to prevent obtaining incorrect estimates, such as setting a mask value for PDOP. The influence of other factors on the neuro-fuzzy system, such as distance of the remote stations from the base station and the time at which data is logged, is under investigation.

## 6. REFERENCES

Ghalehnoee, A. (2002). Improving determining the location of a moving body on map by low cost GPS receiver . Student conference on research and development proceedings , Malaysia.

Kennedy, Michael (2002). *The global positioning system and GIS.* Taylor and Francis.

Leick, A. (1995). *Satellite GPS surveying.* 2nd edition, Wiley-InterScience.

Lin, Chung-Jie (1996). Fuzzy processing on GPS data to improve the position accuracy. IEEE symposium on soft computing intelligent systems and information processing, pp557-562.

Sang, J. ; Kubik, K. ; Zhang, L. (1997). Prediction of DGPS corrections with neural networks. Knowledge-based intelligent electronic system, KES'97, proceedings. Volume: 2 , pp355-361.

Trimble, Navigation Limited (1995). *Series 4000 receiver reference manual.*

Zarchan, Paul (1996). Global *positioning system : theory and applications.* Volume : 1 , American institute of aeronautics and astronautics