

Fuzzy Point Averaging of the GPS Position Components

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Abstract

High accuracy is important factor for Global Positioning System (GPS). Because of a variety of factors, all GPS collected points have a certain amount of error. This means that the location on the screen will not reflect the real location. This paper proposes fuzzy point averaging for better accuracy in GPS positioning. Performances between proposed fuzzy and simple point averaging are evaluated and compared. The experimental results with real data in various periods of time for Selective Availability (S/A) on and off, demonstrate that fuzzy point averaging is more accurate than simple point averaging.

Key words: GPS Accuracy, Simple Averaging, Fuzzy Averaging, S/A Error

I. Introduction

The Global Positioning System (GPS) is a radio based navigation system that gives three dimensional coverage of the Earth 24 hours, a day in any weather conditions. The satellites orbit the Earth every 12 hours at approximately 12,600 miles above the Earth. The satellites continuously transmit information towards the Earth. The information is transmitted on two frequencies: L1 (1575.42 MHz), and L 2 (1227.60 MHz). With four or more satellites, a GPS receiver can determine a 3D position which includes latitude, longitude, and altitude.

GPS can be a powerful tool that assists researchers locates points of interest. While GPS provides an easy way to collect latitude and longitude, it is important to remember that there are errors inherent in any GPS collected point. In order to use GPS most effectively, users need to decide on a strategy for dealing with the errors.

The goal of this paper is to obtain better accuracy than simple point averaging from a low cost GPS receiver. The theoretical backgrounds for better accuracy are based on the principle of averaging and fuzzy logic schemes.

This paper is organized as follows. GPS error sources are presented in Section II. GPS accuracy is described in Section III. The fuzzy processings are provided in Section IV. Experimental results are presented in Section V. Conclusions are in Section VI.

II. GPS Error Sources

There are many sources of possible errors that will degrade the accuracy of positions computed by a GPS receiver. The travel time of GPS satellite signals can be altered by atmospheric effects; when a GPS signal passes through the ionosphere and troposphere it is refracted, causing the speed of the signal to be different from the speed of a GPS signal in space. Sunspot activity also causes interference with GPS signals. Another source of error is measurement noise, or distortion of the signal caused by electrical interference or errors inherent in the GPS receiver itself. Errors in the ephemeris data (the information about satellite orbits) will also cause errors in computed positions, because the satellites weren't really where the GPS receiver "thought" they were (based on the information it received) when it computed the positions. Small variations in the atomic clocks (clock drift) on board the satellites can translate to large position errors; a clock error of 1 nanosecond translates to 1

foot or 0.3 meters user error on the ground. Multipath effects arise when signals transmitted from the satellites bounce off a reflective surface before getting to the receiver antenna. When this happens, the receiver gets the signal in straight line path as well as delayed path (multiple paths).

Selective Availability, or SA, occurred when the Department of Defence (DOD) intentionally degraded the accuracy of GPS signals by introducing artificial clock and ephemeris errors. When SA was implemented, it was the largest component of GPS error, causing error of up to 100 meters. SA is a component of the Standard Positioning Service (SPS), which was formally implemented on March 25, 1990, and was intended to protect national defense. SA was turned off on May 1, 2000.

III. GPS Accuracy

GPS accuracy has a statistical distribution, which is dependent on two important factors. The expected accuracy will vary with the error in the range measurements as well as the geometry or relative positions of the satellites and the users.

Satellite geometry can also affect the accuracy of GPS positioning. This effect is called Geometric Dilution of Precision (GDOP). GDOP refers to where the satellites are in relation to one another, and is a measure of the quality of the satellite configuration. It can magnify or lessen other GPS errors. In general, the wider the angle between satellites, the better the measurement. Most GPS receivers select the satellite constellation that will give the least uncertainty, the best satellite geometry.

GPS receivers usually report the quality of satellite geometry in terms of Position Dilution of Precision, or PDOP. PDOP refers to Horizontal (HDOP) and Vertical (VDOP) measurements (latitude, longitude and altitude). A low DOP indicates a higher probability of accuracy, and a high DOP indicates a lower probability of accuracy. Figure 1 shows ‘Poor DOP’ and ‘Good DOP’.

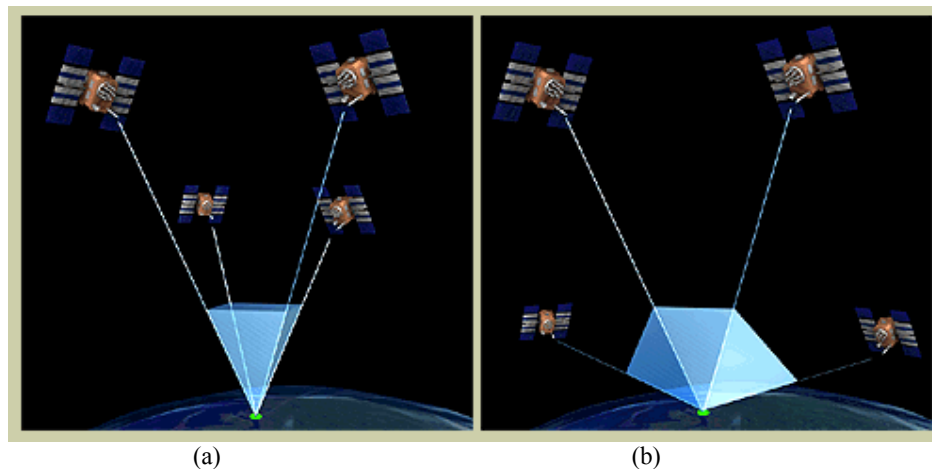


Figure 1. Dilution of Precision: (a) Poor DOP, (b) Good DOP

Another term is TDOP, or Time Dilution of Precision. TDOP refers to satellite clock offset. The relationship between PDOP, TDOP, and GDOP can be expressed as [1,2]:

$$GDOP = \sqrt{PDOP^2 + TDOP^2} \quad (1)$$

Also, the relationship between HDOP, VDOP, and PDOP can be expressed as [1,2]:

$$PDOP = \sqrt{HDOP^2 + VDOP^2} \quad (2)$$

IV. Fuzzy Processings

A. Fuzzy System1 with PDOP

The block diagram of proposed fuzzy system is shown in figure 2. The PDOP and the Sum of Signal to Noise Ratio (SNRs) are used as input fuzzy variables to this fuzzy system. Fuzzy system output is defined as Reliable Factor (R.F.).

PDOP and SNRs are divided into three and four segments for partition the rule space, respectively. R.F. is fuzzified with a singleton membership function. The membership functions are defined as figure 3, where S, M, B, MS and MB express Small, Medium, Big, Medium Small and Medium Big, respectively. Twelve rules in the rule base are defined as table 1.

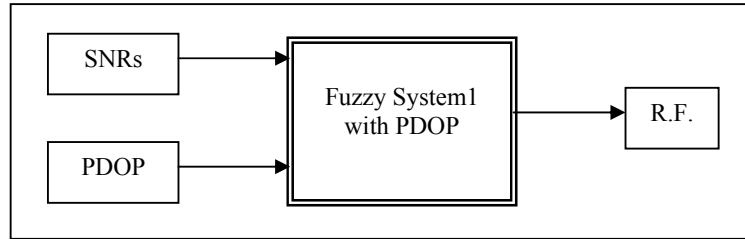


Figure 2. The block diagram of proposed fuzzy system1

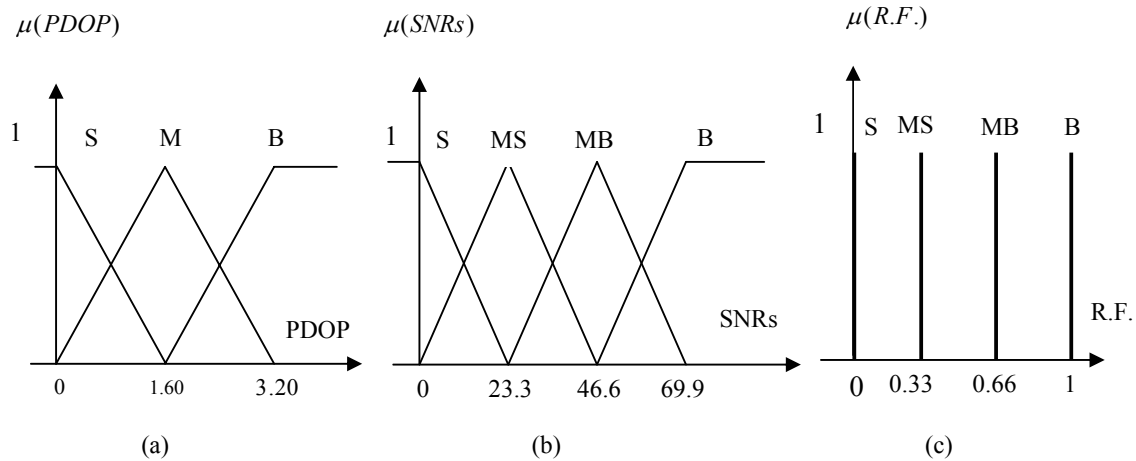


Figure 3. Membership functions: (a) PDOP, (b) SNRs and (c) R.F.

Table 1. Twelve rules in the rule base of fuzzy system1

R.F.		SNRs			
		S	MS	MB	B
PDOP	S	S	MS	MB	B
	M	S	S	MS	MB
	B	S	S	S	MS

The Mamdani-Style method with product is used for the inference process and the center of area method is employed for the defuzzification [3]. Based on the R.F. value, the more accurate positions are selected.

B. Fuzzy System2 with GDOP

The block diagram of proposed fuzzy system is shown in figure 4. The GDOP and the SNRs are used as input fuzzy variables to this fuzzy system. Fuzzy system output is defined as R.F. that according to its value, the more accurate positions are selected.

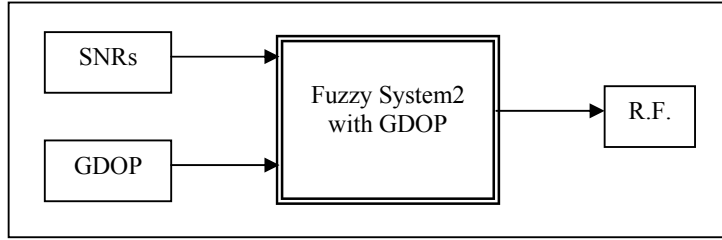


Figure 4. The block diagram of proposed fuzzy system2

GDOP and SNRs are divided into three and four segments for partition the rule space, respectively. R.F. is fuzzified with a singleton membership function. The membership functions are defined as figure 5.

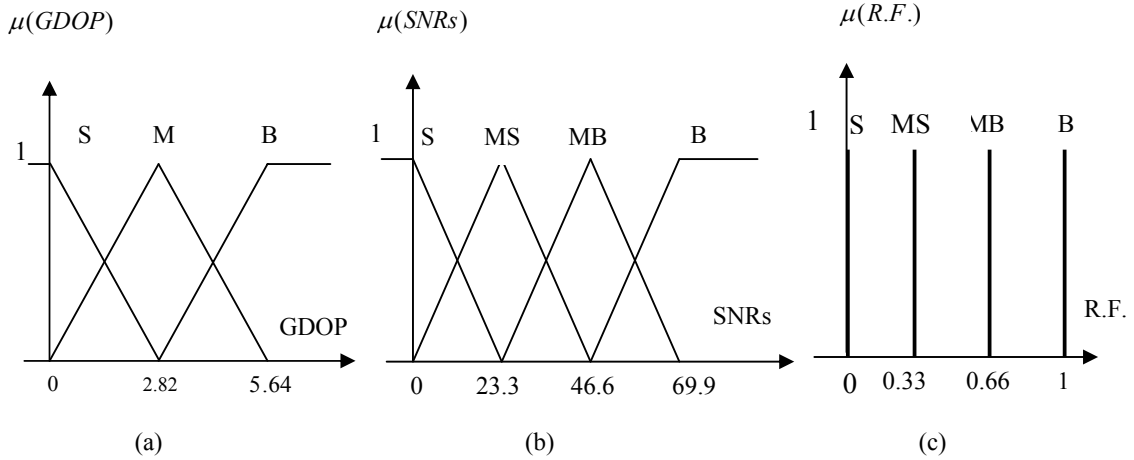


Figure 5. Membership functions: (a) GDOP, (b) SNRs and (c) R.F.

Twelve rules in the rule base are defined as table 2.

Table 2. Twelve rules in the rule base of fuzzy system2

R.F.		SNRs			
		S	MS	MB	B
GDOP	S	S	MS	MB	B
	M	S	S	MS	MB
	B	S	S	S	MS

The Mamdani-Style method with product is used for the inference process and the center of area method is employed for the defuzzification [4]. Based on the R.F. value, the more accurate positions are selected.

V. Experimental Results

At first, 36000 (10 hours) the original fix positions were collected on the building of Computer Control and Fuzzy Logic Research Lab in the Iran University of Science and Technology. Data collecting has been in two different periods, before and after 1st May 2000

(June to December 1999, and July to September 2001). Then, position components were averaged with various periods of time and also with various R.F. using a recursive algorithm based on the following equations [5]:

$$\begin{aligned} X_{n+1} &= \frac{n-1}{n} X_n + \frac{1}{n} x_{n+1} \\ Y_{n+1} &= \frac{n-1}{n} Y_n + \frac{1}{n} y_{n+1} \\ Z_{n+1} &= \frac{n-1}{n} Z_n + \frac{1}{n} z_{n+1} \end{aligned} \quad (3)$$

Where X_{n+1} , Y_{n+1} and Z_{n+1} are average of position components, n is the number of sampled frames at averaging and x_{n+1} , y_{n+1} and z_{n+1} are positions of measured at the time $n+1$. The results are shown as the following. Table 3 shows summary of experimental results of the three systems for 10800-fix positions with R.F. equal to 0.20, before S/A was turned off.

Table 3. Error reduction by fuzzy and simple point averaging for 10800-fix positions with R.F. equal to 0.20 (S/A on)

Time of Averaging	Simple Averaging	Averaging with Fuzzy System1	Averaging with Fuzzy System2
0	174.2003	174.2003	174.2003
8 Minutes	72.6534	53.2406	49.3554
10 Minutes	65.6333	47.8844	45.6586
30 Minutes	39.4292	26.6107	24.6981
40 Minutes	27.2583	20.4732	16.6241
2 Hours	16.4509	14.0863	12.0026
3 Hours	11.9045	9.6103	3.9838

Where “Error” is defined as follow:

$$Error = \sqrt{(X - X_{ref.})^2 + (Y - Y_{ref.})^2 + (Z - Z_{ref.})^2} \quad (4)$$

Where X , Y and Z are average of position components. Also, $X_{ref.}$, $Y_{ref.}$ and $Z_{ref.}$ are components of reference point or desired point. Table 4 shows summary of experimental results of the three systems for 2880-fix positions with R.F. equal to 0.15, after S/A was turned off.

Table 4. Error reduction by fuzzy and simple point averaging for 2880-fix positions with R.F. equal to 0.15 (S/A off)

Time of Averaging	Simple Averaging	Averaging with Fuzzy System1	Averaging with Fuzzy System2
0	17.1458	17.1458	17.1458
5 Minutes	11.3178	11.3178	11.3178
15 Minutes	5.0050	5.0050	4.9109
48 Minutes	1.5302	1.2245	0.6089

As shown in table 3 and table 4, fuzzy point averaging decreases better than simple point averaging position components error.

VI. Conclusions

In this research, was studied and saved position parameters received from a low cost GPS engine both in presence and absence of intentional errors (S/A). This measurement was performed for a known position. The results demonstrated that fuzzy point averaging of the raw position components improved the measurement accuracy better than simple point averaging. So that position measurement error before turning off the S/A, was decreased from more than 170 to less than 4 meters by fuzzy point averaging. Similarly, the position error was reduced to less than 1 meter with turning off the S/A, while it was about 17 meters before fuzzy point averaging.

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Dr. M.R.Mosavi received his B.S., M.S., and Ph.D. degrees in Electronic Engineering from Iran University of Science and Technology (IUST), Tehran, Iran in 1997, 1998, and 2004, respectively. He is currently faculty member of Electrical Engineering Department of Behshahr University of Science and Technology (BUST) as assistant professor. His research interests include Artificial Intelligent Systems (AIS), Global Positioning Systems (GPS), Geographic Information Systems (GIS) and Remote Sensing.