IMPROVING GPS ACCURACY BY USING GENETIC ALGORITHMS

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ABSTRACT

The global positioning system (GPS) constellation comprises 24 Earth-orbiting satellites, which transmit radio signals [1]. These signals can be received on earth with a relatively inexpensive device. GPS has revolutionized the science of positioning earth measurement. One important part of revolution is the accuracy.

The GPS is used to estimate the coordinate of the user position, by the required parameters for navigation algorithm evaluation, which is extracted from the row data in the receiver measurements [2]. Least square algorithm (LSA) is one of the important methods, which can be used to estimate the position coordinate of the GPS antenna. Note that, the estimated position includes the errors contributed in the pseudurange measurements. However, these errors affect the accuracy of antenna position estimation by the navigation algorithms.

In this paper genetic algorithms (GAs) are utilized to improve the accuracy of the user position. GAs is one of the best search and optimization methods [3]. In addition, GAs are used to improve the GPS performance, reduce the overall run time and achieve faster convergence to the optimal solution. The problem is how to construct the mathematical relations of the fitness function. Because the fitness function is responsible to achieve the optimal solution. However, in this paper the fitness function determination is done according to LSA. Furthermore, two approaches are discussed and applied for initial population generation (random, and linspace generations), also a comparison between the two types was made. The conventional LSA can be used to estimate the user position for only 4 and 5 satellites. While, by using GAs it is also possible to estimate the user position even for 3 satellites.

KEYWORDS

GPS, least square algorithm, genetic algorithms, and MATLAB.

1. INTRODUCTION

The GPS consist of a constellation of 24 operational satellites, these satellites are arranged so that four satellites are placed in each of six orbital planes to ensure continuous world wide converge.

The idea behind GPS is rather simple. If the distance from a point on the earth (GPS receiver) to three GPS satellites are known along with the satellite locations, then the location of the point (or receiver) can be determined by simply applying the well–known navigation algorithms (least-square algorithm), which is one of the most effective method for estimation of user position. The accuracy obtained with this algorithm was until recently limited. This limitation was due to the effect of several types of errors according to those origination at the satellites, at the receiver and that are due to signal propagation [1].

GAs are a class of general-purpose search methods combining elements of direct and stochastic searches, which can make a good balance between exploration and exploitation of the search space. In GAs accumulated information is exploited by the selection mechanism, while new regions of the search space are explored by means of genetic operators. In conventional genetic algorithms, the crossover operator is used as the principal operator and the performance of a genetic system is heavily dependent on it [3]. The mutation operator which produces spontaneous random changes in various chromosomes is used as a background operator.

The GAs provides good precision for the user position with at least 3- satellites. Where the conventional algorithms used at least 4-satellites.

2. LEAST–SQUARE ALGORITHM

It is an iterative method unique solution provides the coordinate of the user position and clock bias from given information. This information is the coordinates of at least 4-satellites and their ranges, and presents the number of iterations to the algorithms, which calculates the displacements of the GPS receiver coordinates [1, 2].

The satellite positioning refers to positioning by means of satellites; it dose not mean positioning of satellites. In Figure (1) the coordinate of the jth satellite positions known as (x_j, y_j, z_j) within the coordinate system that rotates with the earth, known as Earth–Centered Earth-Fixed (ECEF) system. The ECEF Origin coincides with the center of mass (C) of the earth and the user

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position coordinate *(x, y, z)*. The vector (*r*) presents the positions of the satellite with respect to the center of mass of the earth, the vector (*R*), which represents the distance between the user and the center of the earth, and (*P*) is a range vector between the satellite and the receiver.

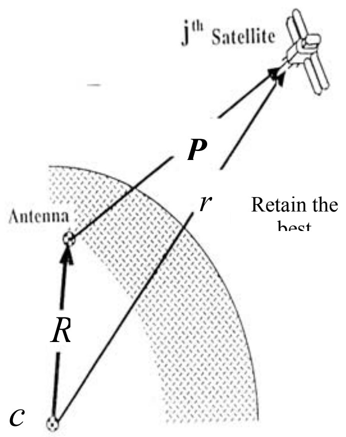


Figure (1) present the user position vector

The vector of satellite to receiver is:

` $\boldsymbol{P = r - R}$

The magnitude of the vector *P* is:

$$\boldsymbol{P} = \left|\boldsymbol{r} - \boldsymbol{R}\right| \qquad \textbf{(1)}$$

The distance *P* computed by measuring the propagation time from the satellite to the user receiver antenna, which means the time difference between the time of generated signal from the satellite at t_1. And the time arrives to the receiver at t_2 the propagation time is represented by Δt. If the satellite clock and the receiver clock were perfectly synchronized the correction process yield the true propagation time by multiplying this propagation time Δt by the speed of light the true satellite to receiver distance can be computed however, the satellite and receiver clocks are generally not synchronized. Each clock of the receiver and the satellite has a basic error from system time [1, 2]

The timing relationships are shown in Figure (2) Where the system time at which the signal left the satellite denoted by (T_s), (T_u) is the system time at which the signal reached the user receiver, (δt) is the offset of the satellite clock from system time, (t_u) is the offset of the receiver clock from system time .The timing of the satellite depends on the free running clock which offset from system time.

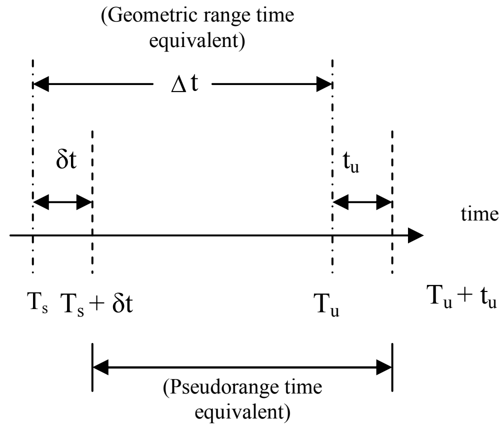


Figure (2) Range measurement timing relationship

Where the geometric range is:

$$\boldsymbol{P = c(T_u - T_s) = c\,\Delta t}$$

Therefore the pseudorange is:

$$\rho = \mathbf{c\ [(T_u + t_u) - (T_s + \delta t)]}$$

Thus the difference between the satellite and the receiver clock offset denoted by the pseudorange ρ, then Eq. (1) can be rewritten as:

$$\rho - ct = \left|\boldsymbol{r} - \boldsymbol{R}\right|$$

If we know approximately, where the receiver is, then we can denote the offset of the true position (x, y, z) by displacement ($\Delta x, \Delta y, \Delta z$) and we can obtain the position offset ($\Delta x, \Delta y, \Delta z$) as linear functions of the known coordinates and pseudorange measurement [4]. Using the approximate position location ($\hat{x}, \hat{y}, \hat{z}$) and time bias estimate $\hat{t}$, an approximate pseudorange could be calculated as follows:

$$\hat{\rho}_j = \sqrt{(x_j - \hat{x})^2 + (y_j - \hat{y})^2 + (z_j - \hat{z})^2} + c\hat{t}$$

$$= f(\hat{x}, \hat{y}, \hat{z}, \hat{t})$$

As stated above, the unknown user position and receiver clock Offset are considered to consist of an approximate component and an incremental component:

$$x = \hat{x} + \Delta x$$
$$y = \hat{y} + \Delta y$$
$$z = \hat{z} + \Delta z$$
$$t = \hat{t} + \Delta t$$

Thus,

$$f(x,y,z,t) = f\left(\hat{x} + \Delta x, \hat{y} + \Delta y, \hat{z} + \Delta z, \hat{t} + \Delta t\right)$$

This latter function could be expanded about the approximate point and associated predicted receiver clock offset ($\hat{x}, \hat{y}, \hat{z}, \hat{t}$) using a Taylor series and the expansion has been truncated after the first-order partial derivatives to eliminate nonlinear terms, Where

$$\hat{r}_j = \sqrt{\left(x_j - \hat{x}\right)^2 + \left(y_j - \hat{y}\right)^2 + \left(z_j - \hat{z}\right)^2}$$

Substituting and rearranging the above expressions with the known quantities on the left and unknowns on right yields [2]

$$\hat{\rho}_j - \rho_j = +\frac{x_j - \hat{x}}{\hat{r}_j}\Delta x + \frac{y_j - \hat{y}}{\hat{r}_j}\Delta y + \frac{z_j - \hat{z}}{\hat{r}_j}\Delta z - c\Delta t \quad \text{……………(2)}$$

For convenience, the above equations were simplified by introducing new variables where

$$\left.\begin{aligned} \Delta\rho_j &= \hat{\rho}_j - \rho_j \\ a_{xj} &= \frac{x_j - \hat{x}}{\hat{r}_j} \\ a_{yj} &= \frac{y_j - \hat{y}}{\hat{r}_j} \\ a_{zj} &= \frac{z_j - \hat{z}}{\hat{r}_j} \end{aligned}\right\} \quad (3)$$

The a_{xj}, a_{yj}, and a_{zj}, terms in Eq. (3) denote the direction cosines of the unit vector pointing from the approximate user position to the jth satellite. Eq. (2) could be rewritten more simply as [2]

$$\Delta\rho_j = a_{xj}\Delta x + a_{yj}\Delta y + a_{zj}\Delta z + c\Delta t$$

Four unknowns: Δx, Δy, Δz and Δt, which can be solved by making ranging measurements to four satellites. The unknown quantities can be determined by solving the set of linear equations below: -

$$\Delta\rho_1 = a_{x1}\Delta x + a_{y1}\Delta y + a_{z1}\Delta z - c\Delta t$$
$$\Delta\rho_2 = a_{x2}\Delta x + a_{y2}\Delta y + a_{z2}\Delta z - c\Delta t$$
$$\Delta\rho 3 = a_{x3}\Delta x + a_{y3}\Delta y + a_{z3}\Delta z - c\Delta t$$
$$\Delta\rho 4 = a_{x4}\Delta x + a_{y4}\Delta y + a_{z4}\Delta z - c\Delta t$$

Finally, These equations can be put in matrix form as,

$$\Delta\rho = H\Delta x \quad (4)$$

Which has the solution

$$\Delta x = H^{-1}\Delta\rho \quad (5)$$

Where H^{1} is the inverse unit vector for each satellite position with initial user position. Then $\Delta\rho$ which is called the residuals measurement, was calculated, $\Delta\rho$ represents the difference between the measured pseudorange after smoothing and calculated pseudorange, Δx is the offset vector that is unknown must be calculated from Eq. (4) during iteration. These offsets are added to the initial user position to produce a new user position.

3. GENERATION OF INITIAL POPULATION

In this paper, two approaches were used to generate the initial population as mentioned before, (see Fig. (3)). It is well known, GAs use a random function (*rand* function in MATLAB) to generate the initial population within a specified range (parameters range) [3]. However, by using random generation the program takes higher run time (about five iterations) to reach the optimal solution, as shown in Fig. (3). While for linspace generation, GAs takes about one or two generations only to reach the optimal solution. This is because of two reasons, the first one is the large difference in parameters value, and the second is that the optimal solution is around ± 200 m from some initial candidate solutions. Therefore, to improve the GPS accuracy and to reduce the number of iterations (reduce the run time). A linspace function (MATLAB function) is used to generate the initial population. for example, to generates 10 equally spaced points between 0 and 1 using linspace function. The output vector will be,

[0, 0.1111, 0.2222, 0.3333, 0.4444, 0.5556, 0.6667, 0.7778, 0.8889, 1.0]

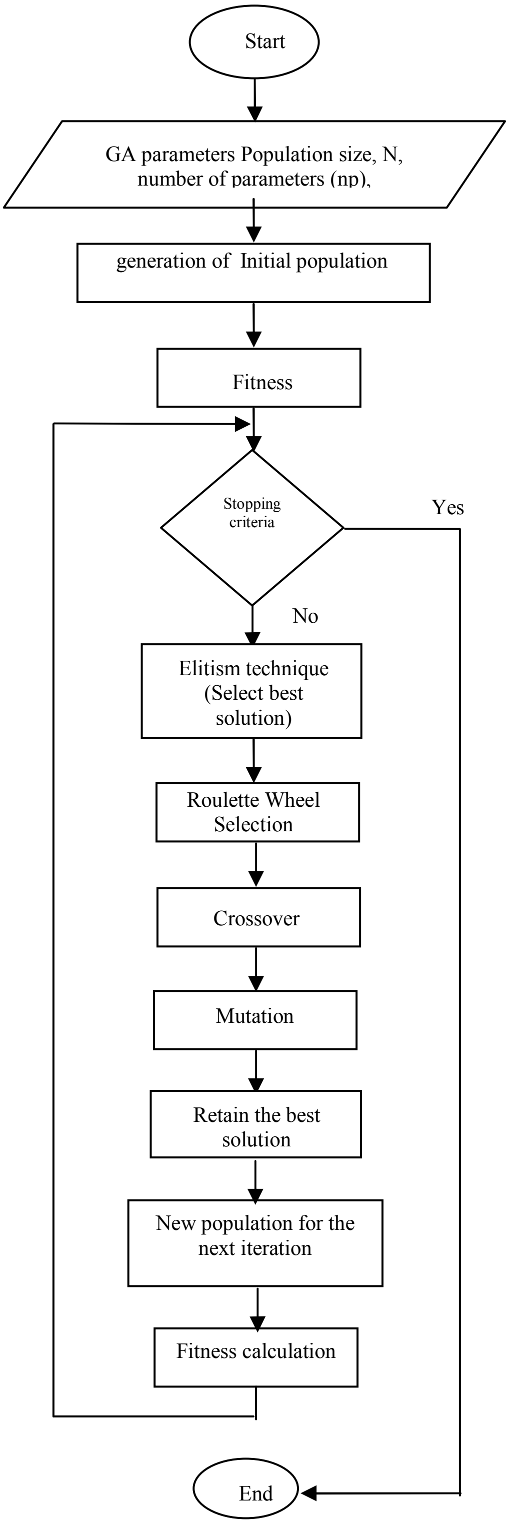


Figure (3) GA operators that are carried in each generation until the required criterion

4. USER POSITION CALCULATION BASED GENETIC ALGORITHMS

The aim of this paper is to find a new algorithm, which is responsible to search for the optimal solution However, the accuracy of the user position depends on two main reasons; the number of the satellites, also ot depends on the types of initial population generation. The LSA is an iterative method and use single initial solution. LSA is used to estimate the user position x, y, and z with clock offset from satellite positions and pseudorange via at least four satellites. Figures (4, 5) shows the GPS positioning error for static user (using *enu* (east-north-up coordinates system), and *upos* functions from MATLAB GPS Toolbox) based on LSA for 4 & 5 satellites.

In this paper, a modified method is obtained by using GAs is used to estimate the location of the GPS receiver with different numbers of the satellites by given their (positions and pseudoranges) with the initial position of the GPS receiver (initial condition) to generate population of points. The column of this population is called the number of parameters which is the coordinates of the user position x, y and z, the row is defined by the size of population and also called the number of solutions (N). The initial population generation process is presented in different ways random, and linspace, which are discussed in section three. After the generation of population, fitness function starts to calculate the fitness value of each individual solution in the population. Figure (3) shows the flow chart of a simple GAs. The fitness function, *f(x)*, is obtained based on LSA, hence referring to Eq. (5),

$$f(x) = \frac{1000}{1 + |\Delta x|}$$

The roulette wheel selection process starts depending on the fitness values of each candidate solution. Then crossover and mutation takes place each one with their probability (p_c, and p_m respectively) [3], the individuals start to exchange their genes to provide a new generation. In this work, the GAs parameters are assumed as, $p_c = 0.7$, $p_m = 0.05$, N=1000, number of parameters ($n_p = 3$), and for 20 generations. In addition, an elitism technique and error stopping criterion [3] are used as shown in Fig.(3).

In general for both types of generations, for cases of 5 and 4 satellites it is clear that the error is reduced and the GPS accuracy is increased as a comparison with 3 satellites as shown in Fig. (4-6). So that, the GPS accuracy increased by increasing the number of satellite (see Fig. (4-6)), and by using linspace generation. Therefore, faster convergence to the optimal solution is obtained by sing linspace generation, while for random generation GAs takes about 5 generations as shown in Fig. (7). This means that GAs gives better solution by employing linspace generation to generate the initial population. In addition, as a comparison with the conventional LSA, GAs gives better solution and more accurate user position for the same number of satellites, as illustrated in Fig. (4-6). In other word, the results employing GAs for the two types of generations (especially for linspace type) is better than the conventional LSA as shown in Fig.(4-6).

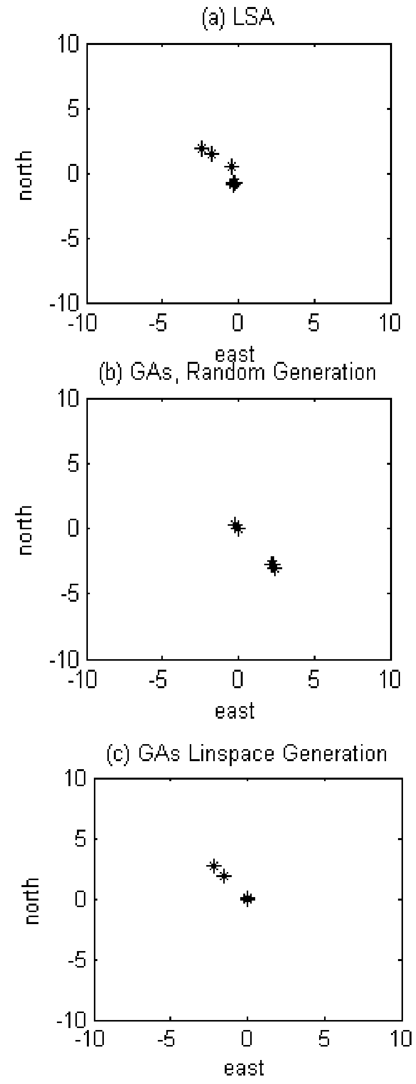


Fig.(4) GPS positoning error, for 5 Satellites.

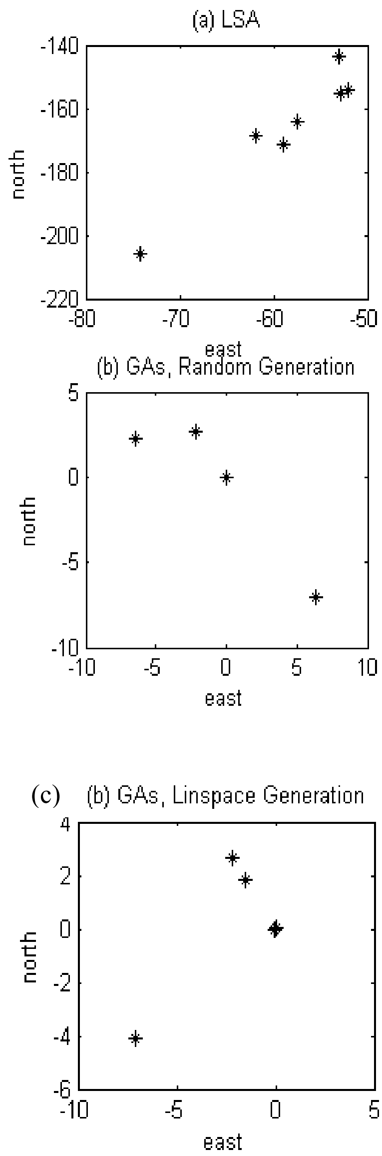


Fig.(5) GPS positoning error, for 4 Satellites.

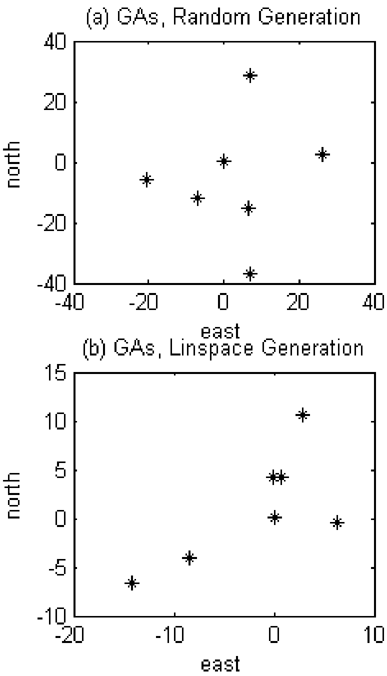
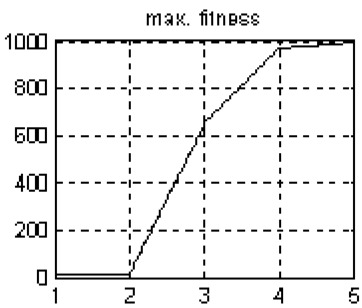


Fig.(6) GPS positoning error, for 3 Satellites.



generation

Fig.(7) Maximum fitness by using genetic algorithms with random generation.

5. CONCLUSIONS

The GPS receiver is divided into two main parts; correlator and navigation processor. The objective of this paper is to build a navigation algorithm as a first step to construct the GPS receiver. The algorithms commonly used by navigation processor, in order to determine the required parameters to estimate the position of the receiver antenna. GAs were used to process the given information from the GPS device in order to reach to the desired solution. However, in this paper the fitness function determination is done according to LSA. Furthermore, two approaches are discussed and applied for initial population generation (random, and linspace generations) There are many advantages of using GAs for finding the position of the GPS receiver (point positioning). GAs gives better solution than LSA, faster convergence to the optimal solution. Especially when employing linspace function to generate the initial population. Furthermore, by employing GAs an optimal solution can be obtained for at least 3 satellites, while LSA gives solution for at least 4 satellites.

6. REFERENCES

[1] Ahmed E. "Introduction to GPS the global positioning system" Artech house Boston London, site, http://www.artechhouse.com (2000).

[2] Stephen B. "An Algebraic solution of the GPS equations" IEEE transactions on aerospace and electronic system, Vol. 21, No. 7, pp. 56-59, (1985).

[3] Mitsuo Gen, and Runwei Cheng, " *Genetic Algorithms and Engineering Optimization*", John Wiley & Sons, Inc., 2000.

[4] Samuel P. Pullen, Per K. Enge, and Bradford W. Parkinson "Global Optimization of GPS Augmentation Architectures using Genetic Algorithms" Department of Aeronautics and Astronautics, Stanford University, site, http:// www.waas.stanford.edu/~wwu/papers/gps/PDF/global_optimize_spp95.pdf (1995).

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