Journal of Geomatics

Vol 8 No. 2 October 2014

Satellite visibility analysis for selecting optimal ground site based on simulated annealing algorithm

M.I. Doma[1], Y.A. Faried[2], A.A. Sharkawi[2] and M.T. Azmi[2]
[1]Civil Engineering Department, Faculty of Engineering, Menoufia University, Egypt
[2]Civil Engineering Department, Faculty of Engineering, Helwan University, Egypt
Email: mohamed.doma@sh-eng.menofia.edu.eg

(Received: Dec 26, 2013; in final form: Mar 26, 2014)

Abstract: Visibility analysis between satellites and ground stations is an important research area due to its influence on satellite communications and navigation. Intervisibility analysis between a GPS receiver and each potentially visible GPS satellite are performed using a number of different surface models and satellite orbit calculations. However, topographic obstruction is still a key issue affecting the positioning quality. The main emphasis of this study is on developing a satellite visibility and quality assessment technique for a global navigation and satellite system utilizing high-resolution 3-D topographical information using simulated annealing (SA) algorithm. By incorporating the proposed method, one can identify an optimal site location for a GPS station. The implementation of the method is described and results are reported.

Keywords: GPS, Satellite surveying, Visibility analysis, Simulated annealing method, GPS networks

1. Introduction

Since the launch of its first satellite in 1978, the global positioning system (GPS) has become one of the most exciting technologies in the past decades and subsequent years (Han and Li, 2010). It successfully fulfills the high-quality positioning and timing needs not only in military applications as it was originally designed for but also in a wide variety of civilian uses (Leick, 2004).

Although only four visible satellites are needed for a GPS receiver's operation, the accuracy of the position triangulation generally increases with increasing the number of visible satellites. For a certain receiver, the number of satellites used in the triangulation process is the key factor in the performance of the receiver. It is typically recommended that a receiver use at least six satellites for triangulation, and there are many cases in which this requirement is attained.

However, there are locations and times in which a GPS user's satellite visibility requirement is not met. If the receiver cannot establish line-of-sight (LOS) with enough number of satellites, its accuracy reduces to a two-dimensional point with an assumed elevation, or it may not work at all. Most of satellite visibility tools perform their visibility prediction algorithms without considering LOS obstructions between the receiving antenna and the satellites that may block the signal. It assumes that receiver is placed at a "bare earth" or open sea. This assumption may be inadequate if the receiver is used in any environment in which there are objects that may block the satellite signal. Those satellites may be hidden from the receiver by terrain or buildings. Some obstructions near a GPS station might be acceptable. For example, station occupation times can be extended to compensate for obstruction (Bill, 2005).

Analytical techniques, such as linear and nonlinear programming, have been used for geodetic science. On the other hand, some heuristic optimization techniques have been started to be used recently in geodetic science such as genetic algorithms, simulated annealing and particle swarm optimization algorithms (Saleh and Chelouah, 2004; Sahabi et al., 2008; Yetkin et al., 2011; Doma, 2013; Doma and Sedeek, 2014).

This research focuses on predicting number of visible GPS satellites at an environment filled with obstacles and to optimally choose receiver position that achieves the best satellites vision using simulated annealing method.

A general framework is described for satellite visibility analysis. Then, the search strategy of the simulated annealing technique, its structural elements and operators are explained. Subsequently, a numerical case study has been applied to assess the performance of the proposed technique. Finally the conclusion and discussion of possible directions for future research are outlined.

2. Site selection

The most important factor for determining GPS station location is the project's requirements (needs). After project requirements, consideration must be given to the following limitations of GPS (Bill, 2005):

- Situate stations in locations that are relatively free from horizon obstructions. In general, a clear view of the sky is required. Satellite signals do not penetrate metal, buildings, or trees and are susceptible to signal delay errors when passing through leaves, glass, plastic and other materials.

- Avoid locations near strong radio transmissions because radio frequency transmitters, including cellular phone equipment, can disturb satellite signal reception.

- Avoid locating stations near large flat surfaces, such as buildings, large signs, and fences, as satellite signals can be reflected off these surfaces causing multipath errors.

3. Satellite visibility analysis

Based on the principle of satellite positioning, the success of a GPS surveying relies on a good network geometry constituted by satellites that are visible to a receiver, topographic obstruction is still a key issue affecting positioning quality (Han et al., 2012). Consequently, a visibility analysis becomes an essential step in evaluating the quality of satellite positioning. The satellite visibility can be typically determined by computing the elevation angles of satellites with respect to a receiver. In a simplified scheme, the receiver is assumed to be located on an infinite plane, and satellites with positive elevation angles are regarded as visible to this receiver. In addition to the satellite visibility and network configuration, the uncertainty in satellite orbits is also a key factor that affects positioning quality (Han and Li, 2010). Figure 1 shows the maximum elevation angle for determining the satellite visibilities.

The visibility of satellites can be determined by a line-of-sight (LOS) analysis between satellites and the receiver using three dimensional data of the obstructions at the receiver environment. The basic method of a LOS analysis is to determine whether any obstruction blocks the sight vector between a view point (i.e. receiver) and a target (Guth, 2004).

Obstructions are objects which block the path between a satellite and receiver. For example, if a desired satellite is at an elevation of 20° and azimuth of 70°, and a building is located at the same elevation and azimuth, the satellite signal will be obstructed. The avoidance of obstructions is very important to the successful application of GPS positioning (see Fig. 1).

3.1 Checking visibility of satellites

The proper functioning of a GPS receiver requires uninterrupted signal reception from at least four GPS satellites. To establish radio contact, an unobstructed direct line of sight path must exist between the receiver and each satellite. GPS radio wave signals however, cannot considerably penetrate sea surface, soil, trees or other manmade structure such as walls, dams, and bridges.

In many cases, this signal shading will be transitory and hence will not severely hamper the positioning. In the inner city streets of urban areas line with skyscrapers, the visibility of the GPS satellites is often limited for extended periods or simply unavailable throughout the observation campaign. This so called “signal outages situation” can also happen in forestry applications with dense canopy area. As in coastal and in land water navigation, transitory signal shading by large topography, wide-span bridges and vessel’s own high-rise structures can also be found depending on the location of the GPS antenna (Yahya and Kamarudin, 2008).

The maximum elevation angle of all obstructions and corresponding azimuth for each will be used to plot the obstruction curve. The next step is to plot sky plot coordinates for all satellites on the same chart. Then we check satellite visibility for each satellite considering that a satellite is considered visible to the receiver if its elevation angle is above the horizon and the sky plot coordinates for that satellite is inside the obstruction curve.

If the elevation angle of the satellite below the horizon or its coordinates is outside the obstruction curve the satellite will be invisible. The following describe the proposed mathematical model for visibility analysis:
The coordinates of all obstructions around the receiver can be written in matrix form:

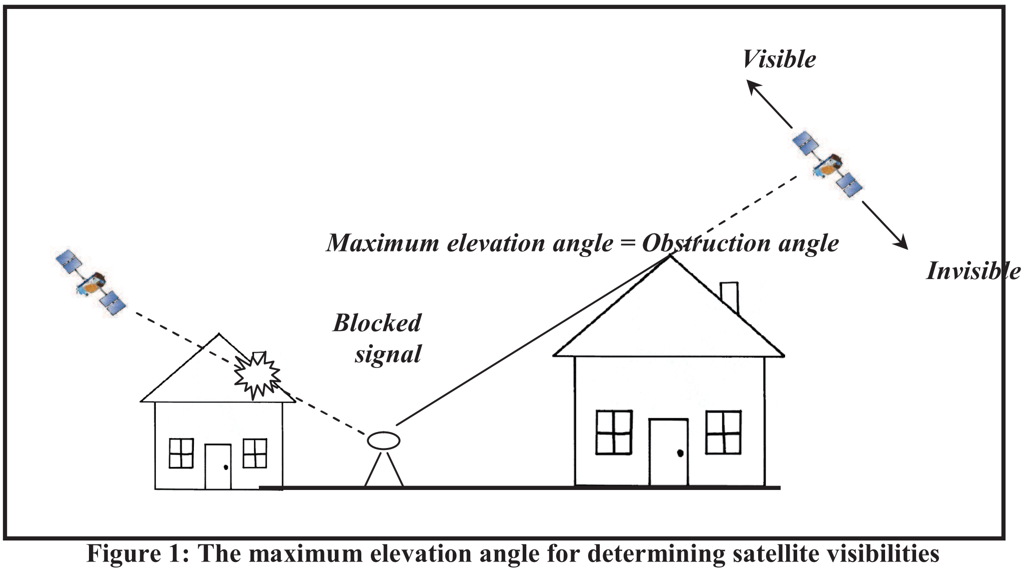

Figure 1: The maximum elevation angle for determining satellite visibilities

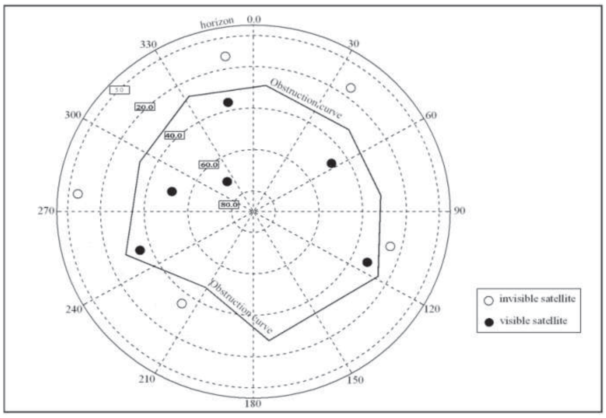

Figure 2: Visible and invisible satellite

$$\mathbf{E_{obs.}}(2\mathbf{o}\times 1) = \begin{pmatrix} \mathbf{e}_{11} \\ \mathbf{e}_{12} \\ \vdots \\ \mathbf{e}_{o2} \end{pmatrix} \quad \& \quad \mathbf{N_{obs.}}(2\mathbf{o}\times 1) = \begin{pmatrix} \mathbf{n}_{11} \\ \mathbf{n}_{12} \\ \vdots \\ \mathbf{n}_{o2} \end{pmatrix} \quad \& \quad \mathbf{Z_{obs.}}(2\mathbf{o}\times 1) = \begin{pmatrix} \mathbf{z}_{11} \\ \mathbf{z}_{12} \\ \vdots \\ \mathbf{z}_{o2} \end{pmatrix} \qquad (1)$$

where E_{obs} , N_{obs} and Z_{obs} : East, north and elevation vectors of obstruction points; e_{mn},n_{mn} and z_{mn} : indicates the coordinates of point (n) in obstruction (m) and o : is the total number of obstructions.

Then the horizontal distance vector from the receiver and each point in obstruction is computed:

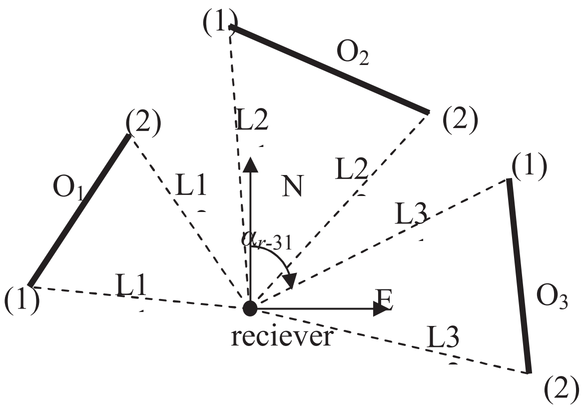

Figure 3: Horizontal distance from receiver to obstructions

$$L_{obs.} = \begin{pmatrix} L_{11} = \sqrt{(e_{11} - e_r)^2 + (n_{11} - n_r)^2} \\ L_{12} = \sqrt{(e_{12} - e_r)^2 + (n_{12} - n_r)^2} \\ \vdots \\ L_{o2} = \sqrt{(e_{o2} - e_r)^2 + (n_{o2} - n_r)^2} \end{pmatrix} \qquad (2)$$

where:

e_r, n_r and z_r : the coordinates of the receiver.

The elevation difference vector will be:

$$\Delta\mathbf{Z}_{obs.} = \begin{pmatrix} \Delta\mathbf{Z}_{11} = \mathbf{Z}_{11} - \mathbf{Z}_r \\ \Delta\mathbf{Z}_{12} = \mathbf{Z}_{12} - \mathbf{Z}_r \\ \vdots \\ \Delta\mathbf{Z}_{o2} = \mathbf{Z}_{o2} - \mathbf{Z}_r \end{pmatrix} \qquad (3)$$

The maximum elevation angle (obstruction angle) for all points in obstructions:

$$\varepsilon_{obs.} = \begin{pmatrix} \varepsilon_{11} = \tan^{-1}\left(\dfrac{\Delta\mathbf{Z}_{11}}{\mathbf{L}_{11}}\right) \\ \varepsilon_{12} = \tan^{-1}\left(\dfrac{\Delta\mathbf{Z}_{12}}{\mathbf{L}_{12}}\right) \\ \vdots \\ \varepsilon_{11} = \tan^{-1}\left(\dfrac{\Delta\mathbf{Z}_{o2}}{\mathbf{L}_{o2}}\right) \end{pmatrix} \qquad (4)$$

Maximum elevation angle of all obstruction and corresponding azimuth for each is obtained and can be plotted as a closed obstruction curve line in a sky plot; this can be done by computing corresponding sky plot coordinates for all points of obstruction:

$$\begin{pmatrix} \mathbf{x}_{11} \\ \mathbf{x}_{12} \\ \vdots \\ \mathbf{x}_{o2} \end{pmatrix} = \begin{pmatrix} \mathbf{e}_r + (90 - \varepsilon_{11})\sin\alpha_{r-11} \\ \mathbf{e}_r + (90 - \varepsilon_{12})\sin\alpha_{r-12} \\ \vdots \\ \mathbf{e}_r + (90 - \varepsilon_{o2})\sin\alpha_{r-o2} \end{pmatrix} \quad \&$$

$$\begin{pmatrix} \mathbf{y}_{11} \\ \mathbf{y}_{12} \\ \vdots \\ \mathbf{y}_{o2} \end{pmatrix} = \begin{pmatrix} \mathbf{n}_r + (90 - \varepsilon_{11})\cos\alpha_{r-11} \\ \mathbf{n}_r + (90 - \varepsilon_{12})\cos\alpha_{r-12} \\ \vdots \\ \mathbf{n}_r + (90 - \varepsilon_{o2})\cos\alpha_{r-o2} \end{pmatrix} \qquad (5)$$

where *x, y* is the corresponding sky plot coordinates of *e, n* coordinates for the obstruction.

In order to perform a satellite visibility analysis, the positions of satellites should be first estimated using almanac or from the IGS Analysis Centers (ACs). The IGS ephemeris data typically consists of satellite positions at evenly spaced times of a week.

In present work the positions of satellites were estimated using the data of Analysis Centers (ACs). The IGS ephemeris data are given at 900 sec (15min) time steps. In current study we interpolate the position of each satellite to provide a reasonable satellite data at equal time steps of (1 min). The Lagrange interpolation method was used to interpolate the given IGS ephemeris data at a high accuracy to utilize the satellites orbits.

By knowing satellite positions, vectors between receiver and any satellite can be estimated. A vector between a receiver and a satellite with an elevation less than the obstruction angle will be blocked by the obstruction. Consequently, the satellite is not visible to that receiver.

3.2 The Lagrange interpolation method

The Lagrange interpolation method described as in the following (Neta et al., 1996). In the Lagrange method there is a set of basis polynomials which enable us to interpolate a set of points with no need to solve a set of linear equations.

These sets of basis polynomials are known as Lagrange polynomials and known as L in (t).

The Lagrange polynomials enable us to find the degree n of a parametric curve which interpolates n + 1 points P_0 , P_1 , P_2 ,……. , P_n at a parameter values t_0 , t_1 , t_2 ,…. , t_n .

The parametric curve can be defined by:

$$P(t) = P_o L_o^n(t) + P_1 L_1^n(t) + P_2 L_2^n(t) + ... + P_n L_n^n(t) \quad (6)$$

Where:

$$L_i^n(t) = \frac{(t-t_o)(t-t_1)\ ....\ (t-t_{i-1})(t-t_{i+1})\ ......(t-t_n)}{(t_i-t_o)(t_i-t_1)\ ....\ (t_i-t_{i-1})(t_i-t_{i+1})\ ......(t_i-t_n)} \quad (7)$$

$$P(t) = \begin{pmatrix} X(t) \\ Y(t) \\ Z(t) \end{pmatrix} \quad (8)$$

The polynomial coefficients P_0, P_1... P_n indicates the value of the satellite coordinates at times t_0, t_1 ...t_n.

Equation (6) can be written in the following form:

$$\begin{pmatrix} X(t) \\ Y(t) \\ Z(t) \end{pmatrix} = L_o^{11}\begin{pmatrix} X(t_o) \\ Y(t_o) \\ Z(t_o) \end{pmatrix} + L_1^{11}\begin{pmatrix} X(t_1) \\ Y(t_1) \\ Z(t_1) \end{pmatrix} + ... + L_n^{11}\begin{pmatrix} X(t_{11}) \\ Y(t_{11}) \\ Z(t_{11}) \end{pmatrix} \quad (9)$$

where:

$X(t_0)$, $X(t_1)$ and **$X(t_{11})$** are the X satellite coordinates at times t_0, t_1,..t_{11}
$Y(t_0)$, $Y(t_1)$ and **$Y(t_{11})$** are the Y satellite coordinates at times t_0, t_1,..t_{11}
$Z(t_0)$, $Z(t_1)$ and **$Z(t_{11})$** are the Z satellite coordinates at times t_0, t_1,..t_{11}
X(t), Y(t) and **Z(t)** are the satellite coordinates at required time t.

A polynomial from the eleventh order is used in this study because it is sufficient to provide a high degree of accuracy in resulting coordinates. The numerical accuracy of using the Lagrange interpolation method has been verified to the 1 cm level (Yahya, 2007).

3.3 Computation of elevation angle and the azimuth of satellite

After computing the final coordinates of the satellite, the satellite's coordinates should be transformed from WGS84 (X, Y, Z) system to the local coordinates system (E, N, UP) using the rotation matrix according to Hofmann-Wellenhof et al., (1997), in order to compute the elevation angle and azimuth of the satellite:

$$\begin{pmatrix} E^j \\ N^j \\ UP^j \end{pmatrix} = \begin{pmatrix} -\sin(\lambda) & \cos(\lambda) & 0 \\ -\cos(\lambda)\sin(\varphi) & -\sin(\lambda)\cos(\varphi) & \cos(\varphi) \\ \cos(\lambda)\cos(\varphi) & \sin(\lambda)\cos(\varphi) & \sin(\varphi) \end{pmatrix} \begin{pmatrix} X^j - X \\ Y^j - Y \\ Z^j - Z \end{pmatrix} \quad \textbf{(10)}$$

where:

E^j, N^j, UP^j : are satellite j coordinates in local coordinate system.

X^j, Y^j, Z^j : are satellite coordinates in WGS84 coordinate system.

λ , φ : are longitude and latitude of the reference station.

X , Y , Z : are station coordinates in WGS84 coordinate system.

The satellite azimuth (α^j) and elevation angle (ε^j) of the satellite from the position of the receiver can then be computed from the following formulae (see fig. 4):

$$\varepsilon^j = \tan^{-1}\left(\frac{UP^j}{\sqrt{(E^j)^2 + (N^j)^2}}\right) \quad (11)$$

$$\alpha^j = \tan^{-1}\left(\frac{E^j}{N^j}\right) \quad (12)$$

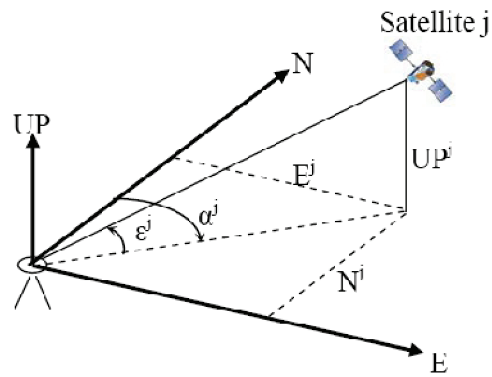

Figure 4: Satellite azimuth and elevation angle in local coordinate system

With known satellite elevation angle and azimuth the sky plot coordinate of each satellite position with respect to a given receiver can be calculated as a function of azimuth and elevation:

$$xs^j = e_r + (90 - \varepsilon^j) \times \sin \alpha^j$$
$$ys^j = n_r + (90 - \varepsilon^j) \times \cos \alpha^j \quad (13)$$

4. Proposed mathematical model

The global optimization problem is then stated as the problem of finding E and N for which the following global maximum is attained:
Maximize:

$$f(E,N) = \sum_{j=1}^{m} \sum_{i=1}^{n} P_{ij} \quad (14)$$

Subjected to:
$$\begin{cases} -\dfrac{\Delta E}{2} \le E \le \dfrac{\Delta E}{2} \\ -\dfrac{\Delta N}{2} \le N \le \dfrac{\Delta N}{2} \end{cases}$$

$$P_{ij} = \begin{cases} \mathbf{1;} & \textbf{if satellite } i(E,N) \in A_{obs} \textbf{ and } \varepsilon_{ij} \ge 0 \\ \mathbf{0;} & \textbf{Otherwise} \end{cases}$$

where:

i : satellite number.

J : time epoch.

ε_{ij} : Elevation angle of satellite *i* at time *j*.

Only constraints can be put on the receiver coordinates to be obtained, including that the coordinates should be within the allowable displacement (ΔE and ΔN) and the minimum number of visible satellite at any epoch should be more than 4 satellites.

After defining the variables and the function by which they are related, the question remains how to achieve the solution. there is a vast literature on global optimization problems successful algorithms can be divided into three main categories: simulated annealing, genetic algorithms and interval-arithmetic-based techniques. Thus, our problem in the present study can be solved using simulated annealing technique.

5. Simulated annealing algorithm

Simulated annealing began with Metropolis et al., (1953), as an iterative heuristic method developed from analogy with the process by which crystalline networks self-construct.

In practice, simulated annealing can only guarantee its convergence to the global optimum in a finite number of iterations. In addition, for highly complicated problems with a large number of variables, it is essential that the method be considered together with the appropriate parallel programming techniques.

Let us suppose a function ***f*** depending explicitly or implicitly on some parameters ***x*** (possibly subject to some restrictions). The global optimization problem, i.e., the determination of the optimum ***x*** within the search domain *D* that makes the objective function ***f*** reach the global maximum, is formulated as:

$$\begin{cases} \max f(x) \\ subject\ \ to\ \ x \in D \end{cases} \quad (15)$$

The simulated annealing method solves the global optimization problem iteratively by means the following scheme (Baselga, 2011):

a. ***Initial solution***: Take an arbitrary vector x (belonging to the search domain) and compute the corresponding objective function value ***f(x).*** Define initial agitation amplitude $\boldsymbol{\sigma_0}$.

b. ***Displacement*** (caused by thermal agitation). Gaussian behavior is customarily selected for emulating the free movement of particles: for each component of ***x,*** generate a displacement according to:

$$\Delta x_i \approx N(0, \sigma) \quad (16)$$

where the corresponding probability density function is:

$$\mathbf{pdf}\,(\Delta x_i) = \frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-\frac{\Delta x_i^2}{2\sigma^2}} \quad (17)$$

With $\boldsymbol{\sigma}$ the displacement amplitude for the iteration (initially $\boldsymbol{\sigma_0}$). Displacements are feasible only if the resulting vector x belongs to the search domain ***D***.

c. ***Amplitude reduction*** in the thermal agitation following some cooling scheme. With the decrease of temperature–the course of iterations in our analogy- displacements (18) suffer a gradual decrease in amplitude σ (geometrical decay in one of the most common choices)

$$\sigma = \beta^j\, \sigma_0 \quad (18)$$

with cooling factor $\boldsymbol{\beta}$ (the closer to unity the slower the cooling) and iteration *j.*

d. ***Accept/reject new solution***. The solution taken as the basis for the next iteration is:

$$\begin{array}{ll} x + \Delta x & \textbf{if } f(x + \Delta x) > f(x) \\ x + \Delta x & \textbf{otherwise with probability } p \\ x & \textbf{otherwise} \end{array} \quad (19)$$

Equation (18) emulates acceptance criteria observed in nature. The acceptance of states of lower energy (lower *f*) is undoubtedly reasonable; however, it has also been observed that in some rare cases (i.e., with low probability *p)* the material occupies temporarily a state of somewhat higher energy in the search for still lower energy levels. This observed feature seems to be important to prevent the algorithm from falling into local optima.

e. ***Go to step 2*** and consider again thermal agitation, cooling, and acceptance criteria. Slop the algorithm when the finishing criterion is verified: e.g., when the displacement amplitude is below a desired value.

If the defined cooling process is slow enough, then the algorithm output is the global minimum of function ***f*** within the search domain ***D****,* i.e., the solution to the posed Eq. (14). A necessary (though not sufficient) condition for global optimum is that successive executions of the algorithm provide the same result.

For more detailed information on the simulated annealing method, refer to more specific sources in the literature (e.g. Van Laarhoven et al. 1987; Pardalos, and Romeijn, 2002).

A new program was developed using MATLAB7; this program can calculate satellites position at specified observation period based on IGS data, and with known obstructions coordinates the program can test if any satellite will be visible to the receiver or not. The program during optimization stage (using SA) creates the search space (within the allowable displacement). For each location the corresponding obstruction curve is plotted. Then the program checked the number of visible satellites from the first epoch to the last is and evaluates the objective function value. The SA will run until the global optimization satisfied. The program also uses DOP values as a measure of quality for any solution.

The program can output different charts (satellite visibility and sky plot….etc.) for any given site and for the optimum site. The Flow chart of the program is given in fig. 5.

6. Case study

A permanent GPS station is to be developed at the shown proposed area. Surrounding obstructions with different heights prevent the establishment of a direct radio contact between the receiver and satellites.

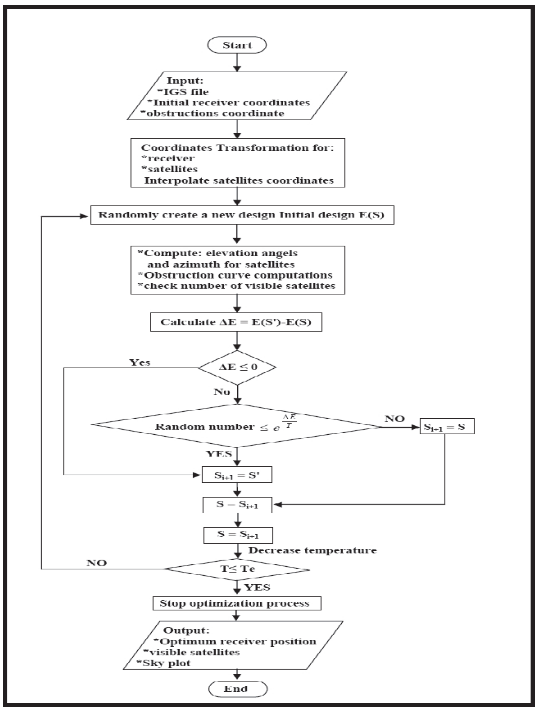

Figure 5: Program flow chart

It is well known that the receiver observes a satellite only if a direct line of sight path exists between the receiver and the satellite. Since the satellite orbits are known, the satellite visibility will change with the change in receiver position with respect to obstruction. So the main goal is to find the optimum position for the GPS station that observes a maximum number of satellites.

There are eleven obstructions with different heights around the proposed area as shown from figure 6. Each obstruction is represented by two points. Coordinates of all points are related to (O) origin point (the initial receiver position). The receiver is allowable to move in East and North direction by a displacement of (ΔE) and (ΔN) respectively.

The simulated test area is located in Cairo city in Egypt (at λ = 31.3245°, φ =30.1237°).

Satellite visibilities for a 24-h period on July 2, 2013, have been analyzed for six test sites in this area using the proposed approach and the GPS almanac file at week1726.

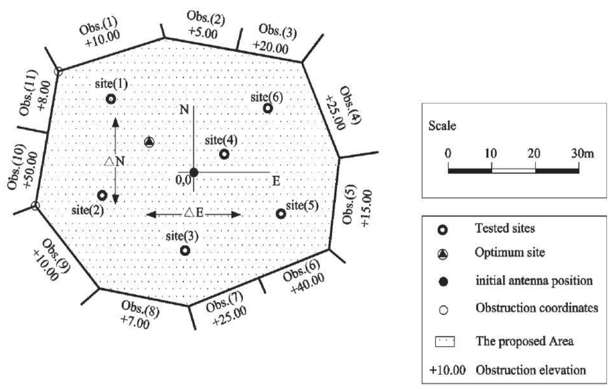

Figure 6: Layout of the study area

Figure 7 shows the satellite visibility considering a flat plane (no obstructions at the site):

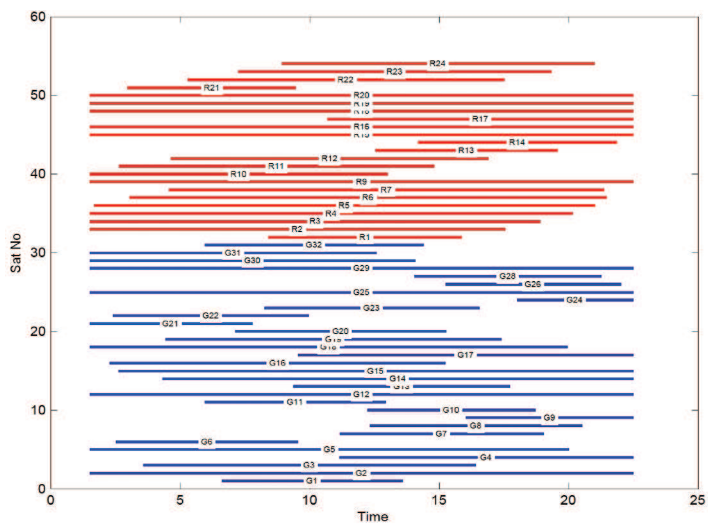

Figure 7: Satellite visibility considering a flat plane

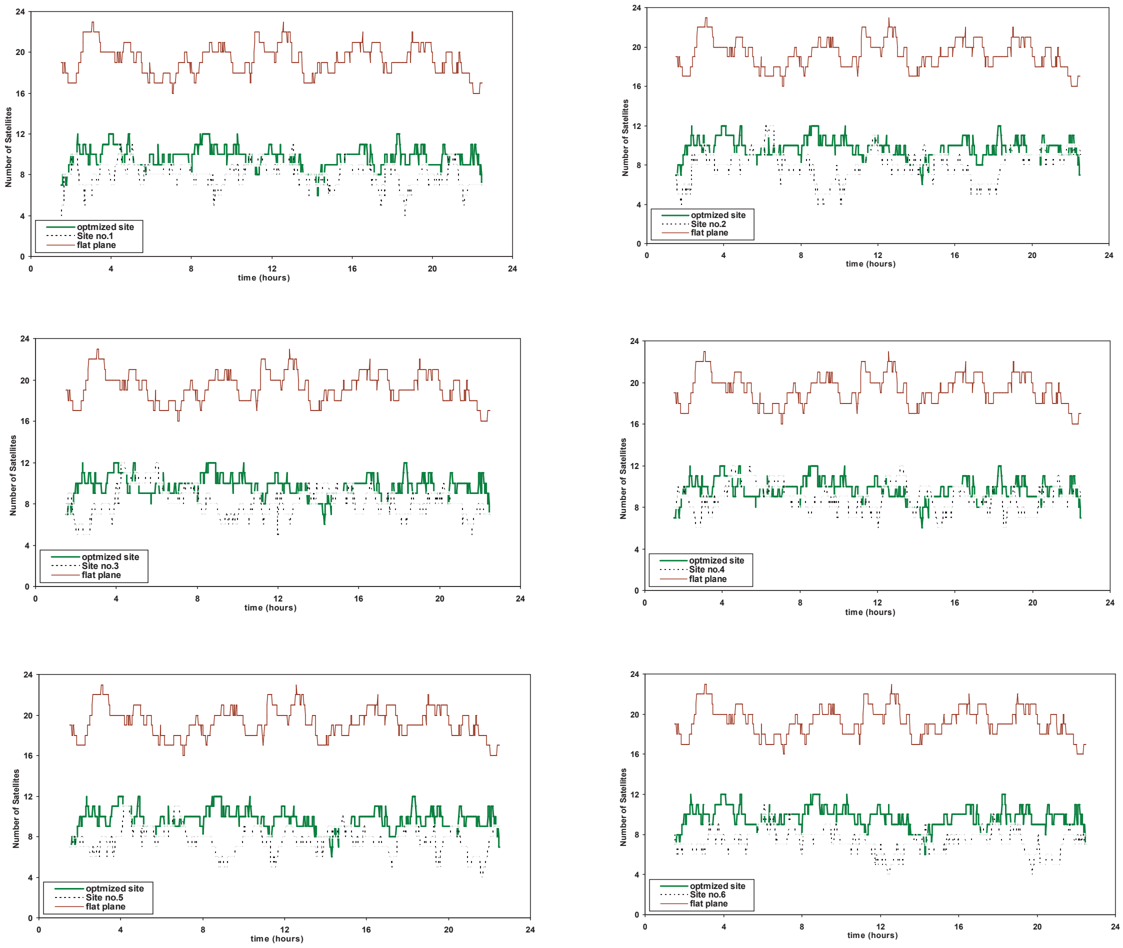

Figure 8: The predicted numbers of visible satellite during the day

Table 1: Number of visible satellites and corresponding DOP values

Site no	Min. number	Max. number	Average number	HDOP	VDOP	TDOP	PDOP	GDOP
1	4	11	7.57	3.924	2.213	3.213	4.505	5.533
2	3	11	7.22	----	----	----	----	----
3	4	11	7.13	4.086	5.039	5.106	6.487	8.256
4	5	12	8.36	3.616	2.445	3.118	4.365	5.364
5	4	10	7.26	4.983	4.402	5.339	6.649	8.527
6	4	10	6.91	4.489	2.402	3.609	5.091	6.241
Optimum	5	11	9.05	2.939	2.253	2.574	3.703	4.510
Flat plane	16	23	19.29	1.496	0.771	0.707	1.683	1.825

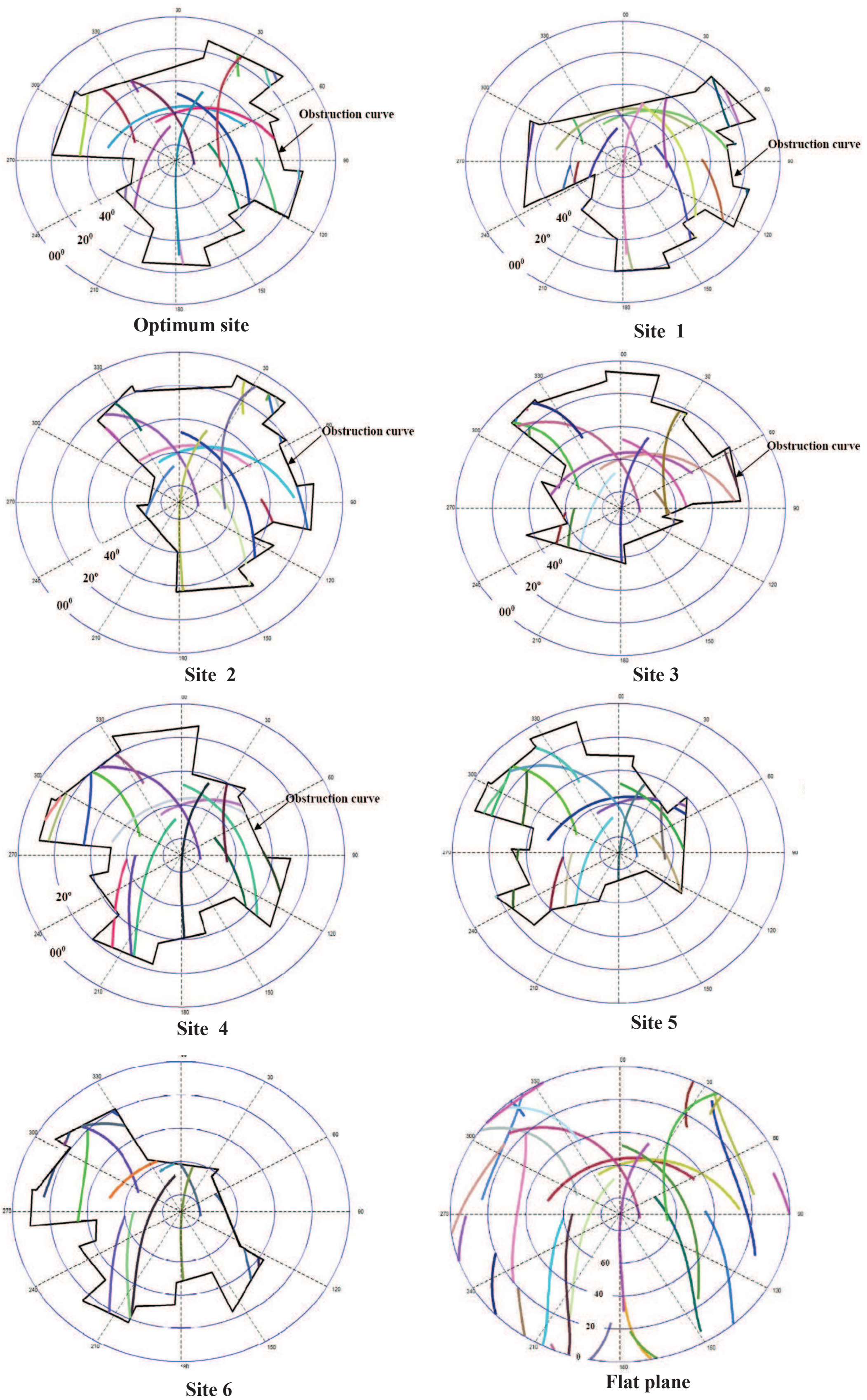

Figure 9: Sky plot for all site

As can be seen from table 2, the optimum site has the best DOP values (minimum values) compared with the other sites (Note: the optimum site is for a given observation period). The GDOP value is equal to 4.51 which considered a good DOP value (2-5). Also we can see that all other sites have a moderate DOP values (5-10). The minimum number of visible satellite is very important because most of GPS specifications require at least 5 satellites to be visible. This condition applies only for the optimum site and site 4.

Table 2: DOP ratings (Ranjbar1 and Mosavi, 2012)

Rating	DOP Value
Excellent	1-2
Good	2-5
Moderate	5-10
Fair	10-20
Poor	>20

We can also note for site 2 the minimum number of satellites is 3 satellites, this number is less than the minimum number required for position determination. So this site will be rejected and no DOP values were calculated for this site.

With respect to site 4 the maximum number of satellites equal 12 which is the maximum one. The maximum value is not the key factor in deciding which site to be the optimum because this value may occur at once during the observation period. The average number during observation period is to be considered. Also the minimum number was considered to check position determination requirements.

7. Summary and conclusions

With rapid advance in space-based positioning technology, GPS has become increasingly popular among surveyors and engineers worldwide. Proper functioning of a GPS receiver requires uninterrupted signal reception from at least four GPS satellites. GPS radio wave signals however, cannot considerably penetrate sea surface, soil, trees or other manmade structures such as walls, dams, buildings and bridges. Nonetheless, in the inner city streets of urban areas line with skyscrapers, the visibility of the GPS satellites is often limited for extended periods or simply unavailable throughout the observation campaign.

The objectives of this study are to analyze the satellite visibility at the randomly established ground sites, to determine the optimal ground site using simulated annealing algorithm. The experimental results show that the new algorithm indicates a good approach for optimum site selection based on visibility analysis.

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