Optimization of baseline configuration in a GNSS network (Nile Delta network, Egypt) – A case study

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Abstract: When starting any GNSS measurements, there is a need to establish a survey plan with the required optimal baselines. The optimal GNSS baselines can be chosen by solving the geodetic second-order design (SOD). The particle swarm optimization PSO is used widely to solve geodetic design issues. This work employed the particle swarm optimization (PSO) algorithm, a stochastic global optimization method, to select the optimal GNSS baselines. The optimal baselines satisfy the set criterion matrix at a reasonable cost. The fundamentals of the algorithm are presented. The effectiveness and usefulness of the technique are then demonstrated using a Nile Delta GNSS network as an example. In some cases, we have to observe many GNSS benchmarks with limited instrumentations. PSO represents a powerful tool for optimizing baseline to get the required accuracy with limited capabilities (like limited receivers). The PSO algorithm, a stochastic global optimization approach, was used in this paper to find the best observation weights to measure in the field that will match the predetermined criterion matrix with a fair degree of precision. The method's fundamentals are presented with an actual geodetic network over the Nile delta in Egypt. In the current work, two survey strategies were applied. One represents a case with 9 GNSS receivers (high capability), and another one represents the tested survey plan with limited GNSS receivers (3 receivers, low capability) after applying PSO. By comparing two survey strategies, applying the PSO algorithm to a real Nile delta geodetic network shows its effectiveness on the obtained coordinate accuracy. This obtained accuracy ranged from 2 mm to 3 mm in X, Y, Z, and 3 mm in height. Also, the linear closure error between known and estimated coordinates improved to be 1.4 cm after applying PSO.

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1 Introduction

The primary goals of geodetic network optimization are to create a geodetic survey that achieves a desirable level of positioning accuracy, high reliability, and low cost [1] in geodesy, where deformable objects must be closely monitored. Deformation monitoring is used to observe the behavior of a deformable object over short or long time intervals. Optimizing a deformation monitoring network allows us to create an observation plan that meets all of the network's pre-defined and required criteria, such as precision [2]. Most technical operations, such as mining and building, require geodetic networks. Also, it is vital for researching natural occurrences like crustal motions. The geodetic network can monitor, implemented, established, and maintained based on its stable and identifiable locations positions. The positions have to associate with a known coordinate reference system. To achieve these goals, the geodetic network should be constructed to meet the requirements of each goal, which include precision, dependability, and cost [3].

Analytical approaches such as linear and non-linear programming and simulation methods are utilized to solve geodetic network optimization challenges. Global optimization approaches like the genetic algorithm (GA) and the particle swarm optimization (PSO) algorithm, on the other hand, are increasingly being employed to handle geodetic network optimization problems nowadays [4].

Estimating the minimum or maximum of one goal function under certain conditions is optimization. The aim function in the geodetic deformation network, for example, will be on, which reflects network quality (precision, dependability, and cost).

The variables in the optimization design problem under examination are called optimization variables:

1. The datum points are the variables. The coordinates are to be fixed in the network in the ZOD (Zero Order Design).
2. The configuration matrix that explains the relationship between observations and the deformation model in the FOD (Frist Order Design) is the variable (A), representing the network's shape.

3. The SOD's variable is the matrix of observation weights (P).
4. The A-matrix of observations and the P-matrix of their corresponding weights are the variables in the THOD (Third Order Design).

The P-matrix will be used as the variable in this study since we are interested in the SOD problem in geodetic networks design.

To find optimal solutions in an appropriate timescale, heuristic techniques are applied. They're utilized to solve large-scale problems that can't be solved in an optimal or timely manner. On the other hand, a heuristic does not ensure convergence to the global best solution. On the other hand, a good heuristic may yield the best solution, or at least a near solution [5]. The method works by progressively refining an existing solution until the user is satisfied with the results. The issue with this method is that it frequently yields a local rather than a global optimum. It becomes required to employ global optimization methods to obtain the global optimum. Particle Swarm Optimization PSO algorithm is an example of global optimization approaches.

Crustal deformation analysis based on geodetic measurements is normally done by comparing the estimated positions of monitoring network stations at various time intervals. As a result, the network's quality is critical in ensuring the network's ability to verify its primary goal [6]. Because GNSS delivers location and time information with great accuracy anywhere on the Earth, it is extensively employed in establishing geodetic networks. GNSS techniques are commonly utilized in geodetic applications to determine three-dimensional (3D) coordinates [7]. One of the most challenging aspects of GNSS network optimization is determining the best baselines to measure in the field to meet the specified optimality criteria. Because the configuration of the measured GNSS baselines has a significant impact on the operation of a geodetic GNSS network, an effective design of the GNSS baselines may provide a network with acceptable precision and reliability while maintaining a low GNSS campaign cost [8]. It is critical to plan ahead of time while establishing a geodetic network.

SOD deals with the determination of the weights of network measurements. SOD is interested in which observations and with what precision should be achieved in the network [9].

It is employed in this context to determine the accuracy of both geodetic and non-geodetic observables or the weight matrix P, resulting in accurate estimations of all unknown parameters as near to some provided idealized counterparts, such as the criteria matrix. The matrix P generated from the SOD solution may guide the selection of instrumentation or observational methodologies [10]

A design approach usually results in a network observation strategy as well as some advice on measurement performance. If the observation plan is accessible, redesigning and optimizing an existing network is also possible [11].

Eberhart and Kennedy devised and introduced PSO in 1995, and it is based on the social intelligence of a group of birds or other animals. The PSO is more objective and simple than other optimization techniques; it's used in various domains, including function optimization, neural network training, and fuzzy system control. Doma and Sedeek [9] used genetic algorithms (GAS) and PSO, which are heuristic optimization techniques and were applied to geodesic horizontal deformation monitoring networks to solve a second-order design problem

Doma [10] used Kuang's network to investigate the efficacy of particle swarm optimization (PSO) to solve complex optimization problems for SOD. To select appropriate baselines in the Kuang network, Odam et al. [13] used the Butterfly Optimization Algorithm (BOA), a new Artificial Intelligence approach. [14] aimed to achieve a second-order design of a GPS network that could be used to monitor distortion in the sense of the desired accuracy and potentially low cost using the PSO method. The previous work tested PSO on a theoretical Kuang network. But, there is no test for applying PSO on actual observations. In the present work, the PSO optimization technique for the baseline configuration in GNSS was applied to a real geodetic network in Egypt. We want to know if we can reach the same accuracy level with a minimum receiver number using the PSO optimization technique. In the following description, we will show the basics of the PSO method. Then, applying the technique to Nile Network is performed.

2 GNSS surveying network problem formulation

A GNSS network differs from a traditional survey network in that it does not require inter-visibility between stations. In GNSS surveying, GNSS receivers are used to map an area by building a network of these coordinated points after determining the positions of the points for an area to be surveyed. These points, referred to as control stations in surveying, are fastened to the ground and located by an expert surveyor based on the nature of the terrain and the survey's requirements. At least two receivers are necessary to watch GNSS satellites concurrently, with one receiver positioned on each station. The following is the mathematical equation of the GNSS network problem as follows [15].

2.1 The GNSS network problem's mathematical equation

Most precise GNSS-based positions are achieved when all satellites are tracked as long as possible, and all possible baselines are measured and recorded in the network. In practice, this is extremely difficult due to cost and time constraints. As a result, the best survey design must be used to achieve the required design criteria at the lowest possible cost. The covariance matrix of the observed vector between these two stations is the immediate result of the observation.

$$\sum_{L_i} = \begin{pmatrix} \sigma^2_{\Delta x} & \sigma_{\Delta x \Delta y} & \sigma_{\Delta x \Delta z} \\ \sigma_{\Delta x \Delta y} & \sigma^2_{\Delta y} & \sigma_{\Delta y \Delta z} \\ \sigma_{\Delta x \Delta z} & \sigma_{\Delta y \Delta z} & \sigma^2_{\Delta z} \end{pmatrix} \quad (1)$$

The total weight matrix P in adjustment is:

$$P = \begin{pmatrix} P_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & P_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & P_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & P_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \ddots & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & P_n \end{pmatrix} \quad (2)$$

Where $\sum_{L_i}$ is the covariance matrix of the observed vector i, $P_1, \ldots, P_n$ are the inverse of covariance, and n is the number of observed vectors.

In optimization problems, P matrix of observation weights and A matrix acts as the geometry of the network. In case the two matrices are known, the covariance matrix of the unknowns is given by Doma [16]

$$Q_x = (A^T PA)^{-1} \quad (3)$$

The cofactor matrix could take any shape that is required. It might, for example, follow the criterion matrix of [17], which corresponds to zones of absolute certainty and relative circular form, or it could simply be a diagonal matrix (although it is not possible in practice). Let us determine the degree of approximation to the needed solution using the Frobenius norm—which offers the Euclidean distance between matrices [12]. As a result, the global optimization issue is identified as the problem of finding the weights in P, Equation (4), for which the global minimum is found

$$min \left\| Q_f - Q_x \right\| = min \sqrt{\sum_i \sum_j ((Q_f)_{ij} - (Q_x)_{ij})^2} \quad (4)$$

As with geodetic positioning networks, to attain the required accuracy with an optimal design of the observation weights (Popt.), a properly chosen precision criterion has to be converted into requirements on the unknown parameters to be optimally solved. In the geodetic network optimal design literature, optimization means minimizing or maximizing an objective function representing the network's goodness. The goodness of a geodetic network can be measured by precision, reliability, strength, and cost [10]. Only precision criteria are considered in this paper.

3 Algorithm of particle swarm optimization

Each individual in the PSO algorithm is referred to as a "particle," representing a potential solution. Due to the variability of some particles in the tracing space, the algorithm achieves the optimal solution. The particles move across the solution space to seek the best particle, regularly changing their locations and fitness; the objective function regulates the flying direction and velocity. A population (swarm) of birds (potential solutions, individuals, or particles) is randomly initialized with values of 0 and 1 in binary PSO. It indicates that each particle is made up of a one and a zero, signifying the presence or absence of a corresponding coefficient in the cost function. The current positions of these particles are represented by (P) [18]. The cost function is then used to calculate the fitness values of these particles (Equation 5). Each particle's best location (PBest) and the global best position of all particles (GBest) are calculated using these fitness ratings. The velocity of each particle (v) is changed iteratively, as shown below [19].

$$v_{ij}(t+1) = w(t)v_{ij}(t) + c_1 r_1 \left[GBest_j(t) - P_{ij}(t)\right] + c_2 r_2 [PBest_j(t) - P_{ij}(t)] \quad (5)$$

where,
i is the index of particle in the population;
j is the index of bits in the binary string of each particle;
t is the iteration number;
r_1, r_2 are two uniform random values in [0,1];
c_1, c_2 are two constant acceleration coefficients
$w(t)$ is time varying inertia weight.

In the computation of the new velocity values, a non-linear inertia weight (w) is utilized to offset the effect of the present velocities

$$w(t) = w_{min} + (w_{max} - w_{min})\left(\frac{t_{max} - t}{t}\right) \quad (6)$$

Where
w_{max}, w_{min} are two constant experimental parameters,
t_{max} is the maximum number of iterations.

After each particle's velocity has been computed, the position of each particle is updated by applying the current velocity to the particle's previous position:

$$x_i(t+1) = x_i(t) + v_{ij}(t+1)) \quad (7)$$

Until a specified convergence threshold is attained, the three processes of velocity update, position update, and fitness calculations are repeated.

The use of the PSO algorithm to determine the optimum observation weights (SOD) in geodetic networks is justified in this study.

4 Test area

In Helwan, Egypt, the National Research Institute of Astronomy and Geophysics (NRIAG) established the Nile Delta geodetic network. This network aims to be used in surveying work and to study the crustal deformation in the Nile Delta and its surrounding area. The GNSS observations for any network have some difficulties. Clock errors, weather conditions, time of day, atmospheric delay, orbit errors, and mask angle are some of the problems encountered throughout the observations. Other difficulties include establishing a high-quality survey plan in order to achieve the required precision with limited GNSS receivers. In our study, the Nile Network has nine stations which require 9 GNSS receivers to be observed. So, first, a survey plan has been designed to observe all points of the Nile Network together with 9 GNSS receivers. The first survey plan used 6 hours of observations from 18 o'clock to 24 o'clock on day 28-04-2020. We use 6 hours according to National Geodetic Survey (NGS) Specifications [20].

On the other hand, in some cases, allowable GNSS receivers are less than the number of observed points. So, it is unavailable to occupy all points with GNSS receivers simultaneously. In this case, we need to prepare a survey plan to get the required accuracy with the limited and minimum number of receivers. To prepare this survey plan, we have to know the required optimal baselines. The PSO optimization were tested in the Nile Delta network to get a survey plan with only three GNSS receivers (minimum number of receivers) and compare the results with the first survey plan with allowable 9 receivers. The period of used data from 28 April to 1 May 2020 were used for this test. By applying PSO technique we get the optimal baselines required to achieve mm accuracy with minimum GNSS receivers. The survey plan has been established to observe GNSS measurements for the optimal baselines with only 3 GNSS receivers. This period has been divided into nine sessions, each with 6 hours of GNSS observations. The GNSS geographic coordinates of the Nile Delta network stations are displayed in Fig 1. Session by session, the data was processed, and normal equations for each session were saved. The processing steps were carried out using Bernese advanced scientific software version 5.2 [21]. Accurate coordinates of network points were obtained as follows:

To prepare the data for final processing, a series of actions must be completed. The following are the various steps:

1. Convert all raw data to RINEX format (Receiver Independent Exchange Format).
2. Orbit file download and preparation: day by day precise orbits and weekly Earth orientation parameters are downloaded from IGS (International GNSS Service). The precise orbits are translated into the celestial reference frame and recorded in the Bernese standard orbit file format after the clock information is retrieved.
3. Coordinate propagation to the current epoch.
4. When working with Rinex files, double-check the types of receivers and antennas.
5. Use ionosphere-free code to calculate receiver clock offsets and keep it in observation files (this is the only step where code observations are used).
6. Initiation Baselines: in BPE (Bernese Processing Engine), we have to create baselines before starting the preprocessing stage. The created baselines depend on the common observations between the observed points.
7. Phase preprocessing: in this step, we are trying to model and correct the cycle slips error in GNSS data.
8. The processing stage started with a float solution without fixing any points, and tropospheric refraction was modeled. In the final step, one or more points are fixed to use in the datum definition of the network.
9. Ambiguity handling: Different strategies are applied concerning ambiguity resolution depending on the baseline length. The output from the processing step is the normal equations which include all baselines. The processing is done daily or session by session. All

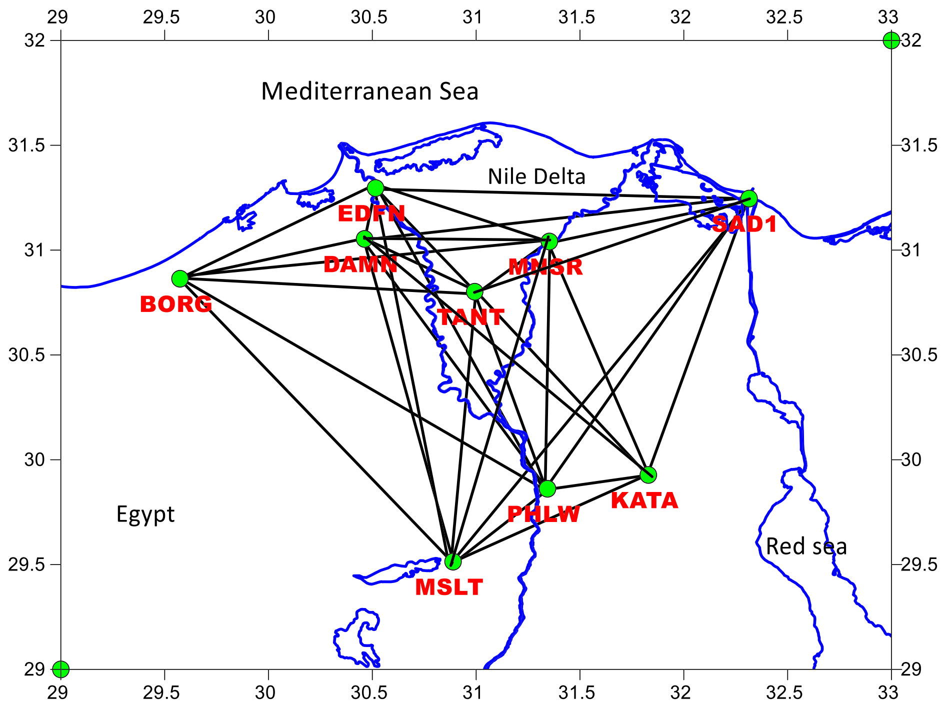

Figure 1: Configuration of Nile Delta network and all possible baselines.

normal equations obtained from sessions have to combine using ADDNEQ sub-program in Bernese.

5 The results and discussion

We try to test applying the optimization technique on a real geodetic network in Egypt in the current work. The Nile delta network consists of nine stations. These stations have their known coordinates estimated from about 3 years of continuous GNSS observations [22]. Table 1 shows the known coordinates of Nile Network points. The configuration of the network is shown in Figure 1. In addition,

Table 1: The known coordinates of Nile Network points.

Stations	*X*	*Y*	*Z*
BORG	4765954.0209	2704546.3511	3252949.3926
DAMN	4714041.4909	2772644.6421	3270984.2956
EDFN	4699483.4708	2769912.0810	3293975.4335
KATA	4700714.1362	2917886.1961	3163657.9446
MSLT	4767120.0815	2851787.0302	3123590.9276
PHLW	4728140.9292	2879662.7841	3157147.3576
SAD1	4613949.7060	2914211.1033	3290440.2103
TANT	4700493.2376	2823555.2987	3247018.7403
MNSR	4671005.8965	2845893.7390	3269812.2915

Figure 1 shows all possible baselines which can be formed between stations. Bernese v5.2 software was used to analyze the GNSS data. The optimization has been tested as follows:

1. First survey plan: All network points were observed together for 6 hours on 28 April 2020. So, all possible baselines were processed using Bernese v.5.2 advanced scientific software, and the coordinates have been estimated. At this case, we have to use nine GNSS receivers. MNSR station is used as a fixed station. The obtained coordinates and their error values are deduced from the first survey plan shown in Table 2. Also, the linear closure error between the estimated and known coordinates is shown in Table 2. It is clear that the accuracy in horizontal is about 2 to 3 mm and vertical 3 mm. Moreover, the average linear closure error is 2 cm.
2. Second survey plan: Applying PSO algorithm optimization for the network to get the required optimal baselines. After selecting the required GNSS baselines, a survey plan is divided into sessions. The session observation time is 6 hours. At each session, three GNSS points have been occupied by receivers. Independent optimal baselines were required for 20 baselines, as shown in Figure 2. There are 9 sessions (see Table 3). Each session contains 6 hours of observations. Using three GNSS receivers, these 20 indepen-

Table 2: Obtained coordinates and RMS for the first technique (all points together).

Stations	*X*	*Y*	*Z*	UP	RMS X in m	RMS Y in m	RMS Z in m	RMS height in m	Linear closure error in m
BORG	4765954.0320	2704546.351	3252949.401	98.07673	0.003	0.002	0.002	0.003	0.014
DAMN	4714041.5098	2772644.646	3270984.306	43.90653	0.003	0.002	0.002	0.003	0.022
EDFN	4699483.4963	2769912.086	3293975.446	25.54341	0.003	0.002	0.002	0.004	0.029
KATA	4700714.1717	2917886.208	3163657.963	495.6038	0.002	0.002	0.002	0.003	0.042
MSLT	4767120.1053	2851787.044	3123590.944	5.34981	0.003	0.002	0.002	0.003	0.001
PHLW	4728140.9567	2879662.79	3157147.371	148.7498	0.002	0.002	0.002	0.003	0.032
SAD1	4613949.7031	2914211.097	3290440.212	38.52567	0.003	0.003	0.002	0.004	0.031
TANT	4700493.2363	2823555.294	3247018.738	51.35328	0.002	0.002	0.002	0.003	0.007
MNSR	4671005.8965	2845893.739	3269812.291	39.51999	0.000	0.000	0.000	0.000	0.005
Average					**0.003**	**0.002**	**0.002**	**0.003**	**0.020**
MAX					**0.003**	**0.003**	**0.002**	**0.004**	**0.042**
MIN					**0.003**	**0.002**	**0.002**	**0.003**	**0.001**

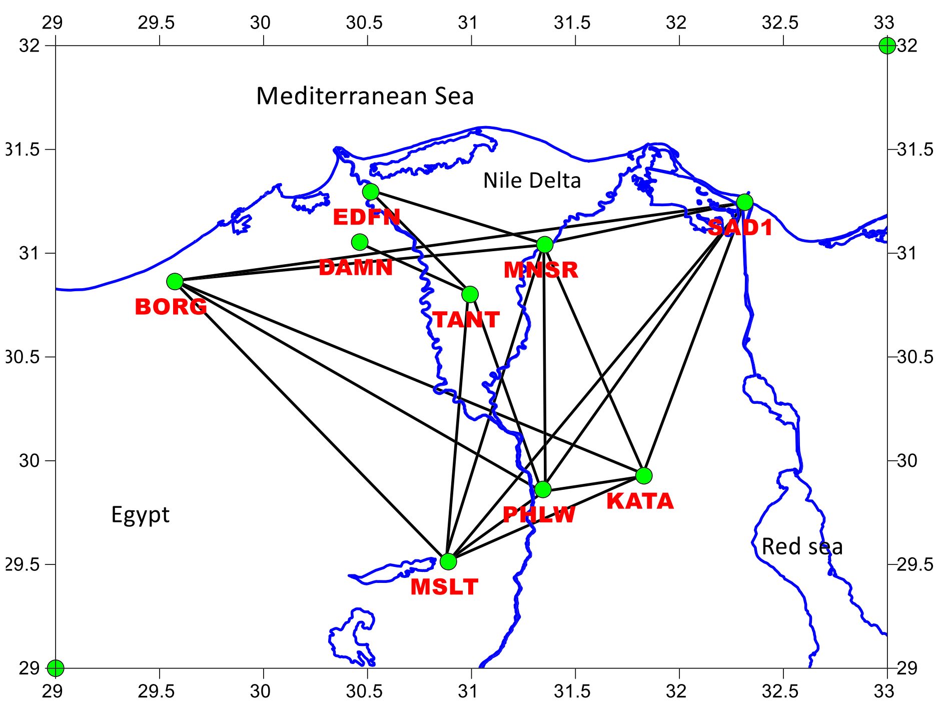

Figure 2: Optimal baselines estimated from optimization.

Table 3: The observation schedule (survey plan 2) has been devised.

Observations schedule			
Session	**Stations**	**Time**	**Date**
1	BORG,KATA,MSLT	From 12 o'clock to 18 o'clock	28-04-2020
2	BORG,PHLW,SAD1	From 18 o'clock to 24 o'clock	28-04-2020
3	BORG,PHLW,MNSR	From 00 o'clock to 06 o'clock	29-04-2020
4	DAMN,EDFN,TANT	From 06 o'clock to 12 o'clock	29-04-2020
5	EDFN,MNSR,SAD1	From 12 o'clock to 18 o'clock	29-04-2020
6	KATA,MSLT,PHLW	From 18 o'clock to 24 o'clock	29-04-2020
7	KATA,SAD1,MNSR	From 00 o'clock to 06 o'clock	30-04-2020
8	MSLT,SAD1,MNSR	From 06 o'clock to 12 o'clock	30-04-2020
9	MSLT,PHLW,TANT	From 00 o'clock to 06 o'clock	01-05-2020

Table 4: Obtained coordinates and RMS for second technique (divided sessions).

Stations	*X*	*Y*	*Z*	UP	RMS X in m	RMS Y in m	RMS Z in m	RMS height in m	Linear closure error in m
BORG	4765954.028	2704546.352	3252949.395	98.071	0.002	0.001	0.001	0.002	0.008
DAMN	4714041.503	2772644.642	3270984.299	43.896	0.003	0.002	0.002	0.005	0.013
EDFN	4699483.487	2769912.082	3293975.436	25.529	0.002	0.002	0.002	0.003	0.016
KATA	4700714.158	2917886.204	3163657.953	495.587	0.002	0.001	0.001	0.002	0.025
MSLT	4767120.102	2851787.042	3123590.938	5.343	0.001	0.001	0.001	0.002	0.001
PHLW	4728140.951	2879662.791	3157147.367	148.744	0.001	0.001	0.001	0.002	0.026
SAD1	4613949.702	2914211.097	3290440.207	38.522	0.001	0.001	0.001	0.002	0.025
TANT	4700493.237	2823555.293	3247018.737	51.353	0.003	0.002	0.002	0.004	0.008
MNSR	4671005.896	2845893.739	3269812.291	39.520	0.000	0.000	0.000	0.000	0.007
Average					**0.002**	**0.001**	**0.001**	**0.003**	**0.014**
MAX					**0.003**	**0.002**	**0.002**	**0.005**	**0.026**
MIN					**0.002**	**0.001**	**0.001**	**0.003**	**0.001**

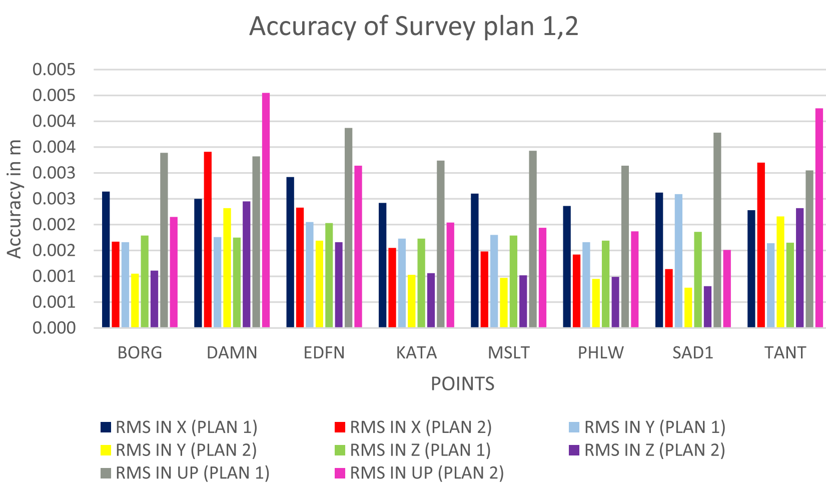

Figure 3: Differences in accuracy between the two survey strategies.

dent baselines were observed in the period from 28 April 2020 to 1 May 2020. Each session was processed individually and then combined solution for all sessions produced using ADDNEQ program in Bernese v. 5. 2. The coordinates of all stations have been estimated as a final product for the combined solution. The estimated coordinates and its errors are shown in Table 4. In addition, the linear closure error values are demonstrated in Table 4. From Table 4, it is founded that the RMS in horizontal ranged from 1 mm to 2 mm and 3 mm in vertical. Also, the average linear closure error becomes 1.4 cm, representing a better closure error than the first survey plan (Before applying the PSO technique).

Some crucial rules should be considered when creating an observation program. These are the rule [23]

- Re-observation of specified baselines: A certain number of baselines should be seen two times to check mistakes.
- At the same time, occupy nearby stations: Because estimation of ambiguity resolution can be solved correctly across short baselines, the nearby stations should be observed simultaneously.
- Connect each session to at least one additional network session via one or more stations where both sessions' observations have been completed.

3. We compare results and accuracy gained from both previous techniques and test the efficiency of OPS optimization. After getting the coordinates of stations from the two previous techniques (all stations together and divided sessions), we studied the efficiency of using PSO optimization by comparing the results of the two survey methods. Figure 3 shows the difference in

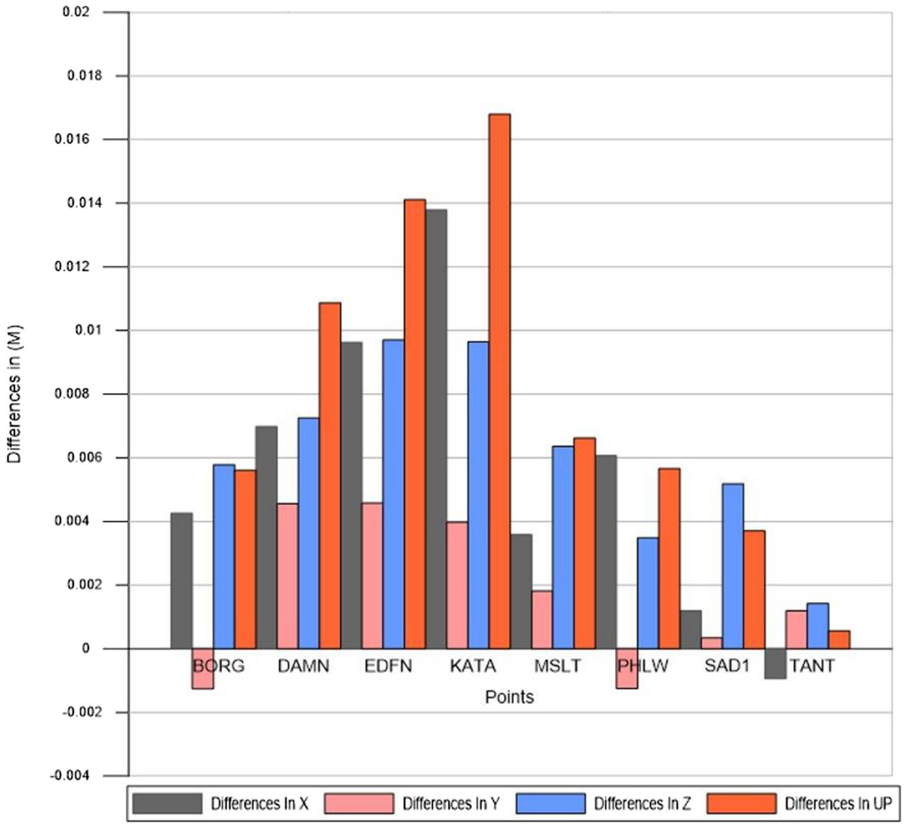

Figure 4: Differences in X, Y, Z, UP components between the two survey strategies.

Table 5: Differences in X, Y, Z, UP components between the two survey strategies.

Stations	The difference in X in m	The difference in Y in m	The difference in Z in m	The height difference in m
BORG	0.004	−0.001	0.006	0.006
DAMN	0.007	0.005	0.007	0.011
EDFN	0.010	0.005	0.010	0.014
KATA	0.014	0.004	0.010	0.017
MSLT	0.004	0.002	0.006	0.007
PHLW	0.006	−0.001	0.003	0.006
SAD1	0.001	0.000	0.005	0.004
TANT	−0.001	0.001	0.001	0.001
MNSR	0.000	0.000	0.000	0.000
MAX	**0.014**	**0.005**	**0.010**	**0.017**
MIN	**−0.001**	**−0.001**	**0.000**	**0.000**
Average	**0.005**	**0.002**	**0.005**	**0.007**

accuracies between the two survey plans. In the case of using nine receivers and observing the nine stations together, It is founded that the average accuracy of the coordinates varies between 2 to 3 mm in X, Y, Z, and 3 mm in height. On the other hand, the second survey plan (after using PSO optimization). It is clear that the accuracy in Y and Z improved to be 1 mm. Also, when comparing the average linear closure error, we found that the closure has been enhanced by applying PSO to be 1.4 cm.

While Figure 4 and Table 5 show the differences in X, Y, Z, and UP components between the two survey strategies. It is noticed that the average differences within 5 mm in X, Y, Z, and 7 mm in height which still acceptable for 6 hours of observations.

We need to observe hundreds or thousands of geodetic points with limited GNSS receivers in large geodetic survey projects. Our finding is that we can get the good accuracy with the limited GNSS receivers by applying the PSO technique. The PSO optimization is significant for the survey plan of any GNSS measurements.

6 Conclusion

Before choosing the number of sessions and creating an observation plan, a list of optimal baselines should be selected. This can be used to build a low-cost network with the required precision and dependability. This research shows that the PSO method may be used to successfully create a survey plan for any geodetic network observations with the required precision. The simplicity and speed of the PSO algorithm are apparent advantages. Non-linear matrix functions can be employed with it. The objective function does not need to be linearized, differentiated, or inversed. Our findings suggest that we can achieve high accuracy with limited and minimum available receivers when using PSO. In this study, the results show that we can get the required accuracy up to 3 mm using a prepared survey plan estimated from the optimization PSO technique. Also, we can see that the average linear closure error between the known and estimated coordinates has been improved from 2 cm (from the first survey plan) to 1.4 cm after using PSO. So, the defect of limited GNSS receivers can be solved by using a trusted survey plan induced from optimization. The previous study applied PSO assuming a theoretical network. Our results represent an attempt to apply the theoretical statistics to a real geodetic network that shows significant efficiency in the accuracy of geodetic observations. So, it is recommended to use PSO to establish a survey plan for the GNSS network.

Conflict of interest: The authors declare no conflicts of interest regarding the publication of this paper.

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