Efficient Tabu Search Procedures for the GPS Surveying

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1 Introduction

The purpose of surveying is to determine the locations of points on the earth. Measuring tapes or chains require that the survey crew physically pass through all the intervening terrain to measure the distance between two points. Surveying methods have undergone a revolutionary change over that last few years with the deployment of the satellite navigation systems. The most widely known space systems are: the American Global Positioning System (GPS), the Russian GLObal Navigation Satellite System (GLONASS), and the forthcoming European Satellite Navigation System (GALILEO). In this paper, it is the use of GPS to establish surveying networks that is being investigated. GPS satellites continuously transmit electrical signals to the earth while orbiting the earth. A receiver, with unknown position on the earth, has to detect and convert the signals transmitted from all of the satellites into useful measurements. These measurements would allow a user to compute a three-dimensional coordinates position for the location of the receiver. To maximize the benefit of using this technique, several procedures based on tabu search techniques have been developed and implemented to find an efficient schedule to improve the performance and explore the search space more effectively [6]. In this paper we implement a tabu search technique applied to GPS surveying networks and the general case of the problem is addressed by presenting several case studies and the obtained numerical results. Our aim is to suggest various local search procedures and to see which one is the best for this problem. The rest of this paper is organized as follows. The general framework for GPS surveying network problem as a combinatorial optimization problem is described in section 2. Then, the search strategy of the tabu search and local search methods are explained in section 3. The implemented tabu search techniques applied to GPS surveying networks is outlined and the general case of the problem is addressed by presenting several case studies and the obtained numerical results in section 4. The paper ends with a summary of the conclusions and directions for future research.

2 Formulating the GPS Surveying Network Problem for Combinatorial Solution

A GPS network is distinctly different from a classical survey network in that no inter-visibility between stations is required. In GPS surveying, after defining the locations of the points for an area to be surveyed, GPS receivers will be used to map this area by creating a network of these coordinated points. These points, control stations within the context of surveying, are fixed on the ground and located by an experienced surveyor according to the nature of the land and the requirements of the survey. At least two receivers are required to simultaneously observe GPS satellites, for a fixed period of time, where each receiver is mounted on each station. The immediate outcome of the observation is a session between these two stations. After completing the first stage of sessions observation and defining the locations of the surveyed stations, the receivers are moved to other stations for similar tasks till the whole network is completely observed according to an observation schedule. The total cost of carrying out the above survey, which is computed upon the criteria to be minimized, represents the cost of moving receivers between stations. The problem is to search for the best order, with respect to the time, in which these sessions can be observed to give the cheapest schedule V, i.e.:

$$Minimize: \ C(V) = \sum_{p \in R} C(S_p)$$

where: $C(V)$ is the total cost of a feasible schedule $V(N, R, U)$; S_p is the route of the receiver$p$ in a schedule; N is the set of stations$N = 1, \ldots, n$; R is the set of receivers $R = 1, \ldots, r$; U is the set of sessions $U = 1, \ldots, u$.

3 Tabu Search and Its Local Search Strategy

Recently heuristic approaches within the field of operational research have been successfully applied to find near optimal solutions to complex real-life problems in a reasonable amount of time. The key objective of this paper is to find an effective solution in a short period of time with close to least cost using tabu search method. Tabu Search (TS) is introduced by Glover [1]. This procedure guides Local Search (LS) methods to overcome local optimality and obtain near-optimal solutions for hard combinatorial optimization problems. TS is defined as a method based on procedures designed to cross boundaries of feasibility or local optimality, which were previously treated as barriers. Attributes that are not permitted to be reinstated are called tabu and maintained in a short-term memory by a list called the tabu-list. In the second stage, the search is carried out among a subset of potentially good solutions and then redirected to a new region in the solution space, which might not yet have been explored. Finally, the adopted stopping criteria in this algorithm is based on a given number of iterations or on the maximum number of iterations allowed without improving the best solution obtained so far. TS has been applied to several combinatorial optimization problems whose applications range from graph theory to general pure and mixed integer programming problems [2]. The achieved success of TS in the above applications is due to its implementations as problem-oriented. Thus, it needs, for each implementation particular definitions of structural

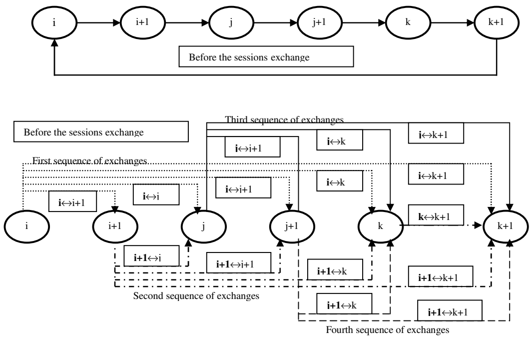

Figure 1: The sequential local search structure (a)

elements such as move, neighborhood, memory structures, stopping criteria, and the initial solution, also, some values of several tuning parameters such as Tabu List (TL), Candidate List (CL) and Tabu Tenure (TT). TS may adopt various stopping criteria [3]. The simplest is to stop after a defined number of iterations. The use of CL strategies offers new ways to avoid extensive computational effort without sacrificing schedule quality. A strict diversification approach keeps track of attribute frequencies over all solutions visited during the history of the search (or of the search within a given region). Then diversification is initiated by seeking to discourage moves to solutions that embody higher frequency attributes or to encourage moves to solutions that embody lower frequency attributes. A strict intensification approach instead keeps track of frequencies over sets of elite solutions. During an intensification phase, high frequency attributes from an elite domain are encouraged or even "licked in". Intensification and diversification should not be independent, but allowed to interact. Tabu list is constructed and updated after each iteration. At the beginning the tabu list is empty, then constructed in tabu-size consecutive iterations and updated circularly in later iterations. In order to implement TS for GPS surveying problem a number of decisions and choices have to be made. Firstly, it involves the definition of the solution space Q and neighborhood structure I, the form of the objective function $C(V)$ and the way in which a starting solution V is obtained. Secondly, the generic choices which govern the working of the algorithm itself, are mainly concerned with the components of the tabu list parameters: length of the TL and its tabu tenure TT, the length of the candidate list CL. For initial solution V we use random generated solution. Local Search (LS) methods is based on the concept of searching the local neighborhood of the current schedule. LS attempts to improve an initial schedule V by a series of local improvement changes (swapping sessions) [5]. Current schedule (solution) is represented by graph. The sessions are represented by nodes and the edges represent the order of observation. A move-generation is a transition from a schedule V to another one $V' \in I(V)$ in one step (or iteration). Metaheuristic techniques may obtain the cheapest schedule through a series of uphill and downhill moves and continue until a stopping criterion is met. The goals of these techniques are to cut down the search space and find a schedule as close to the optimal as possible [8].

In this paper, various local search structures that satisfy the requirements of the GPS network, have been developed and implemented to search the schedule space more effectively. The first procedure [6, 7], shown in a Figure 1, is based on the sequential session- interchange, the potential pair-swaps are examined in the order $(1,2)$, $(1,3), \ldots$, $(1,u)$, $(2,3)$, $(2,4)$, $(u-$

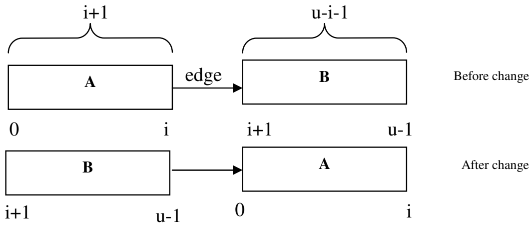

Figure 2: Local search structure (b1) with 1-exchange of edges.

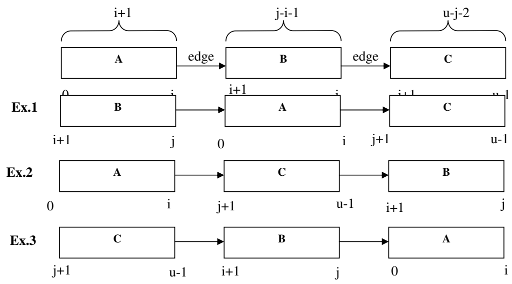

Figure 3: Local search structure (b2) with 2-exchange of edges.

$1, u$) (For comparison reasons this sequential local search procedure is called structure a). In the second procedure as shown graphically in Figure 2, A and B are chains of nodes (part of the solution), while $\{0, i\}$ and $\{i+1, u\}$ are the first and the last nodes of the chains $\{A$ and $B\}$ respectively. In this procedure, only one exchange has been performed of new edge $(u-1, 0)$ each iteration and this can be done by selecting one edge $(i, i+1)$ to be removed (For comparison reasons this local search procedure is called structure b1).

In the third procedure as shown graphically in Figure 3, $\{A, B$ and $C\}$ are chains of nodes (part of the solution), while $0, i$, $i+1, j$, and $j+1, u-1$ are the first and the last nodes of the chains A, B and C respectively. In the case of a 2-exchange, there are several possibilities to build a new solution where the edges $(i, i+1)$ and $(j, j+1)$ are selected to be removed in one iteration (For comparison reasons this local search procedure is called structure b2). The possibilities for new edges are $(j, 0)$ and $(i, j+1)$, $(i, j+1)$ and $(u-1, i+1)$, $(u-1, i+1)$ and $(j, 0)$ where $0 \leq i < j \leq u-1$. In both procedures u is the number of sessions in the observed network. We can combine several LS procedures and thus to construct a new one. We combine the procedure (b2) with procedure (a). First we execute the procedure (b2) and we use the best found solution by it to execute procedure (a) (For comparison reason this local search procedure is called structure b2a).

4 Testing the Tabu Search Performances

This section reports on the computational experience of the TS coupled with various local search procedures using real GPS networks. The first network is a GPS network for Malta

Table 1: Comparison of local search techniques applied to different types of GPS networks

Data	Malta	*RRC*	Seychelles	*RRC*
U	38		71	
C_{INT}	1405	0	994	0
C_{TSa}	1075	23.50	933	6.14
C_{TSb1}	1375	2.14	981	1.31
C_{TSb2}	990	29.54	901	9.36
C_{TSb2a}	945	32.74	887	10.60

and consists of 25 stations [6]. The initial schedule with a cost of 1405 minutes was composed of 38 sessions. The second network is a GPS network for the Seychelles and consists of 67 stations [7]. The initial schedule with a cost of 994 minutes was composed of 71 sessions. The performance of the developed metaheuristic techniques was evaluated with respect to the schedule quality and computational effort using the following measure:

$$RRC = [(C_{INT} - C_{TS})/C_{INT}] * 100$$

Where: RRC is the Relative Reduction of the Cost; C_{INT} is the Cost of the Initial Schedule V_{INT}. C_{TSa} is the Cost of the metaheuristic schedule obtained by procedure a. C_{TSb1} is the Cost of the metaheuristic schedule obtained by procedure b1. C_{TSb2} is the Cost of the metaheuristic schedule obtained by procedure b2. C_{TSb2a} is the Cost of the metaheuristic schedule obtained by procedure b2a.

We use the following parameter settings: candidate list with length 3, tabu tenure $TT = 5$ and fixed number of iterations equal to 1000 for all tests. Analyzing the results in Table 1 shows the advantage the tabu search techniques using various local search procedures, TS technique using local search procedure (b2a) produced best results. With respect to the Malta network with size of 38 sessions, the RRC of the metaheuristic schedule produced by the TS technique is 23.50% using local search procedure (a), compared to an RRC of 2.14% using local search procedure (b1), RRC of 29.54% using local search procedure (b2), and RRC of 32,74% using local search procedure (b2a). In the Seychelles network with size of 71 sessions, the RRC of the metaheuristic schedule produced by the TS technique is 6.14% using local search procedure (a), compared to an RRC of 1.31% using local search procedure (b1), RRC of 9.38% using local search procedure (b2), and RRC of 10.76% using local search procedure (b2a). In this comparison, local search procedure (b2a) gives better results than the other local search procedures for the both type of GPS networks. In the TS method, the selected set of neighbors has an important rule in achieving good results. The size of this selected set is larger in the procedure b2a with comparison to the other procedures. Therefore, the ability of a metaheurtsic technique to obtain an improved schedule with procedure b2a will be greater than with other procedures as can be shown in Table 1. The developed technique has been coded in C++ and implemented on a Pentium 3 with 900MHz speed and 512 MB RAM.

5 Concluding Remarks and Future Work

In this paper, various local search procedures have been developed and compared with local search procedure from [6] and [7] (structure a). The comparison of the performance of the tabu search with these procedures applied to different types and sizes of GPS networks is reported. The obtained results are encouraging and the ability of the developed techniques to generate rapidly high-quality solutions for observing GPS networks can be seen. For the future work, the developed local search procedures in this paper will be coupled with other metaheuristics to search for further improvement and provide a practical comparison, based on the success of the developed tabu search techniques for constructing optimal solutions for large GPS positioning networks which form the basic framework for geomatic information that support all the environmental activities in the countries.

Acknowledgments

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