Dynamic Optimisation of the use of Space Technology for Rapid Disaster Response and Management

Hussain Aziz SALEH
mailto:hsaleh@ulb.ac.beDepartment of Civil Engineering, Faculty of Engineering
Ghent University, Krijgslaan 281 (IDM, S8), B-9000 Gent
hsaleh@mariecurie.org

ABSTRACT

Modern space and information technologies provide valuable tools for the solution of many real-world problems in fields of managing effects of natural and man-made disasters, geomatic engineering, etc. Therefore, the need to develop and optimise the use of these technologies in an efficient manner is necessary for providing reliable solutions. This paper aims to develop powerful optimisation algorithms extending current highly successful ideas of artificial intelligence for developing of the disaster warning network which is a system of satellites and ground stations for providing real time early warning of the impact of the disaster and minimise its effects (e.g., earthquakes, landslides, floods, volcanoes, etc). Such intelligent algorithms can provide a degree of functionality and flexibility suitable both for constructing high-accuracy models and in monitoring their behaviour in real time.

Keywords

Space Technology, Metaheuristics, Artificial Intelligence, Disaster Management.

INTRODUCTION

Many scientific studies have considered the effects of natural disasters, but few have searched for the ideal solutions. Scientific analysis of hazard data is needed before, during, and after a disaster to understand its effect and dimension and to determine how best to respond to existing and potential losses and how to aid with recovery activities. Space and information technologies provide information that is more accurate, facilitate communication, and permit the monitoring of emergency conditions and impacts (Leick, 2004). Therefore, it is important to have good understanding of these technologies which provide reliable solutions to these disasters. This will effectively increase the safety measures and save time and cost. The goal in this research is to create effective response actions to the disasters before impact and dramatically reduce their effects. This will be achieved by implementing the Dynamic Metaheuristic Algorithms (DMAs) based on the ideas of Artificial Intelligence (AI) for optimising the performance of the Disaster Warning Network (DWN). This network is a system of satellites and ground stations which provides real time early warning for protecting lives and property from the damaging effects of both natural and man-made disasters.

DISASTER WARNING NETWORK

The Disaster Warning Network (DWN) uses a network of Reference Stations (RSs) spread over the whole geographic area of the hazard and transmits their observations to a master station. This station computes coordinated corrections for all Global Navigation Satellite System (GNSS) satellites in view of any RS and uplinks them to communications satellites for down link to any user within this geographic area (i.e., this information can made available to the system manger or interested parties on continuous basis). DWN is needed to provide a coverage prediction model to predict accuracy across the entire geographic spread of users and to efficiently determine the required number of RSs to meet the accuracy requirements. Within the context of this paper, DWN is a dynamic problem and can be regarded as a Real Time Multi-objective Optimisation Problem (MOP) (Deb, 2001). Its formulation is as follows:

$$MOP = optimize: f(x) = \{f_1(x), f_2(x), \ldots, f_n(x)\} \quad subject\ to \quad x = (x_1, x_2, \ldots, x_n) \in X$$

Where $f_i(x)$ is the i^{th} objective function to be optimised, x is set of decision vectors and X is the search domain. The term "optimise" means finding the ideal solutions to MOP which are points in the search domain where each objective function corresponds to the best possible value by considering the partial fulfilment of each of the objects. In other words, these solutions are optimal in a way such that no other solutions in the search domain are superior to them when all objectives are simultaneously concerned (Koza, 1992). This paper provides the latest research on how *DMAs* can be effectively applied to identify these solutions which elucidate the trade-off between the conflicting objectives (accuracy, risk, time, etc). This has been observed by knowledge and experience that DMAs are best suited for these types of MOPs as they do not require any derivatives of the objective function in order to calculate the optimum, and have the ability to provide a diverse set of high quality solutions (Saleh, 1999). DWN implements a network of Control Stations (CSs) spread over the whole geographic area of the hazard and transmits their observations to a master station. This station computes updated information for all GNSSs satellites in view of any CS and uplinks them to communication satellites for down link to any end-user within the geographic area. DWN provides this reliable information on continuous basis using the parallel process of coverage accuracy prediction (using Least-Squares equations) and integrity risk simulation functions (using Monte Carlo sampling). The major part of the above process was successfully demonstrated in a simulation program considering all standard ranging errors (e.g., satellite clock, ephemeris, multipath, receiver noise, troposphere and ionosphere, etc.) (Saleh, 1996).

Within the context of MOP, a design solution of DWN is a vector of elements that can be modelled in the GNSS/DWN accuracy and safety predication algorithms. These elements may include reference station sites, provision for independent monitor sites, and additional geosynchronous satellites (which communicate DWN corrections and serve as redundant ranging sources). For example if we have 6 elements: 4 RSs, and 2 geosynchronous satellites placed over the hazard area. Given this list of elements, a design solution is simply a vector of 6 (0-1) entries, where a 1 represents the presence of the relevant elements and a 0 represents its absence. It is worth noting that the addition of new elements (thought up by the human designers) can be handed simply by increasing the length of the design vector. This flexibility is important, as the results of early evaluations and optimisation runs may motivate the designer to think of adding new supporting elements to improve availability. These additional elements could be: the use of geostationary satellites and ranging, additional GPS satellites in the constellation, and variation of the mask angle, etc. Optimisation of entire DWN can be successfully achieved by formulating an objective function which combines accuracy and integrity models analysis into a single top-level measure. This objective function is a measure of the relative quality of each DWN designs produced by a DMA and can be maximised as follows:

$$F_{DWN}(n) = \sum_{s=1}^{N} P_s \left(f_{acy}^{s} - f_{ing}^{s} \right)$$

where

- P_s : A multiplier for measuring the size of the user population near the location *s*.
- f_{acy}^{s} and f_{ing}^{s} : The evaluations of accuracy coverage and integrity performance respectively for user location *s*.
- N: the number of user locations in a given DWN.
- n : the number of obtained DWN designs (iteration number).

The use of complex covariance propagation and Monte Carlo simulation models to produce further accuracy and integrity evaluations for a given DWN (allowing system designers to study performance, risks and cost tradeoffs) requires flexible optimal-search tools that account for the uncertainty present in a changing environment without mathematical constraints on the form of the objective function. DMAs potentially provide this capability as they attempt to produce better real-time solutions and tolerate the noisy evaluations given by these models. The function of a DMA is to find as many optimal DWN designs as possible to reveal and visualize the trade-offs information among different competing objectives. Once such designs are obtained, the higher-level designer will be able to select the final acceptable design by trading the objectives against each other and with further considerations. In the other words, this optimal design of DWN has two features; robust (i.e., performs well over a wide range of environment conditions), and flexible (i.e., allows easy and successful adaptation after the environment has changed).

DYNAMIC METAHEURISTIC ALGORITHMS

Dynamic optimisation is powerful means of effectively exploring the search domain of a problem and finding a more expressive optimal solution that can model more closely and easily the objective functions. A metaheuristic technique is a set of concepts that can be used to define heuristic methods that can be applied to a wide set of different problems. The well-known metaheuristic techniques that have been successfully applied to the use of space technology for designing positioning networks: Simulated Annealing (SA), Tabu Search (TS), Ant Colony Optimisation (ACO) and Genetic Algorithms (GAs) (Osman and Kelly, 1992). These techniques are inspired, respectively, by the physical annealing process, the proper use of memory structures, the observation of real ant colonies and the Darwinian evolutionary process. In this paper, a DMA has been modified to produce an optimal DWN design. Using the initial DWN design (e.g., 6 elements) in iteration 0, DMA starts by producing a set of designs candidates for the initial selected DWN. Then, the quality of each produced DWN design candidates (i.e., value of improvement) are evaluated using both coverage and integrity analyses fed into the cost model. Having found an improvement, the current DWN is replaced by the best-found design in this set, otherwise the current DWN is retained. This process is repeated in each iteration until the value of the best-obtained design stops improving. For *n* iterations, each obtained improvement of a given DWN is added to those conducted previously; thus statistical significance increases with each new iteration. Once the DWN evaluation converges to within an uncertainty tolerance, no further accuracy/integrity evaluations are needed. Therefore, later iterations will run faster than earlier ones. This is the key driver of the DMA optimisation process, as its converge will highly dependent on the skill and experience of the designer for carefully selecting the *structural elements* in which the optimised problem is modelled in order to fit into a DMA framework, and *control parameters* which govern the workings of a DMA itself.

CONCLUSION

This paper constitutes a crucial step towards an overall framework for optimising the use of space and information technologies in many real-life problems based on disaster management. It elucidates how artificial intelligence and computer sciences could be introduced in the space design process in a rewarding manner. The optimisation process of DWN is a computer-intensive model but this will provide the potential converge to the best possible DWN design for a given application. The above model will be dynamically expanded to efficiently provide flexible and computerized procedures for determining high-accuracy models with a higher resolution for other geomatic applications in the field of disaster management and monitoring. Examples of these applications; modelling atmospheric effects, a global high-accuracy gravity field model, etc. Another important outcome of this research is that the early warnings will also be given for industrial, chemical, and biological accidents (e.g., sudden release of waste pollutants, nuclear waste, and oil spills at sea, etc.). A further advanced step of this research is to connect DWN to a database which includes all the geomatic information colleted by other observation techniques (e.g., geographic information systems, remote sensing, photogrametery, surveying, etc) covering the whole geographic area. These further developments should provide extra powerful functionality to tailor DWN to future specific user needs in a very efficient manner and optimise other real-life applications as all these observation techniques complement each other. For example, the use of DWN can be extended to large engineering projects (e.g., dams, bridges, etc) to provide continuous real-time measurements. This can provide information on the displacements and vibrations caused by temperature changes, wind loading, distant earthquakes, etc. These problems tend to be characterised by the presence of uncertainty in the outcomes of the actions that can be performed. This will create an opportunity for real-time structural health monitoring leading to enhanced public safety.

ACKNOLEDGMENT

The author acknowledges the financial support of IncGEO which is a non profit organization funded by the Flemish government.

REFERENCES

1. Deb, K. (2001) Multi-objective Optimisation using Evolutionary algorithms, Chichester: John Wily & Sons, Ltd.,
2. Koza, J. (1992) Genetic Programming, MIT Press, Cambridge, MA.
3. Leick, A. (2004) GPS Satellite Surveying, 3nd. Ed., Wiley, Chichester, England.
4. Osman, I. H., and Kelly, J. P. (editors) (1992) Meta-heuristics: An overview, In: Meta-heuristics: Theory and Applications. Kluwer academic publishers, UK.
5. Saleh, H. A. (1999) A Heuristic Approach to the design of GPS Networks, Ph.D. thesis, School of Surveying, University of East London, UK.
6. Saleh, H. (1996) Improvements to the GPSdemoUCL Simulation Software, MSc Dissertation in Surveying. Dept. of Geomatic Eng., University College London, UK.