Petr STODOLA

POSITION OPTIMIZATION OF COOPERATIVE ARRAYS OF ADAPTIVE GROUND UNATTENDED SENSORS

Reviewer: Vladimír ŘEŘUCHA

A b s t r a c t :

The article is a summarization of the project on the topic "Position optimization of cooperative arrays of adaptive ground unattended sensors". The article deals with the problems of position optimization of unattended ground monitoring systems in the digitized area of interest. The main aim of the mentioned project is finding and checking general procedures and methods to solve this problem. In this article, the present state of solved problems is defined. In short, the article describes design and discussion of the basic principles, procedures and possibilities of this problem solution. Next, the article deals very shortly with sensors models and the possibilities and features of optimization methods used for this problem solution. Also the article pursues some other problems relating to the topic and simulation checking of gathered theoretical pieces of knowledge and conclusions. At the conclusion this article presents practical and theoretical results of the mentioned project and its contribution.

1. Introduction

The article deals with some selected topical problems of the digitized area of interest (DAI) and processing of digitized geographical data. DAI is an essential component of modern conflict solution. Advanced armies gradually inhibit traditional methods of classic field and air training for the benefit of computer modelling and simulation of combat action.

This trend implicates many advantages. Among significant advantages these are considered as follows: smaller operating expanses, lesser damage of nature and hardware, variety of combat and especially higher training safety. The term modelling and simulation of combat action expressed creation of such models (objects and scenes) which are most similar to real combat conditions.

Of course, DAI doesn't serve to computer simulation. In armed conflict it replaces classical "paper" maps and its digitized form is possible to use for different purposes. Digital map features complete information representation of real environment. Therefore, on a digital area it is possible to create a suitable model by computer equipment. This model is applicable to the real environment. Actual state of computer equipment makes it possible to conduct very complex operations in real time.

One of the possible usages of a digitized map is an optimal position of unattended ground monitoring systems (UGMS) in the DAI. UGMS is composed of several sensors which are the main source of actual information from the area of interest. Correct position of these sensors guarantees total monitoring of the DAI.

The aim is to position the monitoring system sensors optimally. The term "optimally" can be understood differently. Generally, it is a solution suiting problem conditions and fulfilling specified goal. The goal in problem of sensor positioning is to monitor the area as large as possible by the smallest possible number of sensors referring to potential possibility of their destruction, failure or detection by the enemy.

The present way of conflict solution is characterised by big dynamics. The emphasis is put on fast countermeasures, force and hardware movements. During movement and in the areas of concentration it is necessary to secure units guarding with minimal claims to manual service. Present monitoring systems uncover intruder in the area of interest and start quiet alarm (that means intruder doesn't know about it). Monitoring systems can guard the area about ten kilometres square.

UGMS are defined as heterogeneous distributed ground detection systems serving to guard the area of interest or objects. The most often, UGMS are used for detection and identification of persons, wheeled and tracked vehicles. UGMS are composed of several (suitably positioned and camouflaged) sensors. The main aim of this article is to introduce practical usable working procedures which ensure suitable (optimal) positioning of constituent monitoring system sensors in the area of interest.

2. The present state of solved problems

2.1. Unattended ground monitoring system

UGMS is a technical electronic device for purposes of ground unattended hidden monitoring of exposed activities and state parameters and activities in progress in the area of interest [1]. The basic exposed features are suitable parts of sound, light, thermal and vibratory spectrum and existence of suitable selected chemical compound.

State parameters are meteorological situation, visibility, presence of smokes, aerosols, chemical materials, biological materials, radiation and radioactive contamination etc. Activities are running of technical devices (vehicles and combat vehicles), weapon systems, sign of engineer works, sign of unit presence etc.

Monitoring system is composed of independent self-contained "intelligent" sensors making input elements of system. Constituent sensors are fully automatic, adaptive, enabled to adjust to environment conditions, remotely controlled in consideration of situation change and cooperative between each other. Parameters, function and technical characteristic of sensors correspond to gathered information about values of physical quantities or information about chemical or biological materials.

Intelligent sensor is detector physical, chemical and biological quantities supplemented by other circuits and function for processing of output electric quantity. Built-in circuits ensure higher resistance against failure, higher precision and application flexibility, higher resistance against negative electrical or physical influences etc.

Block diagram of UGMS is demonstrated in Fig. 1. Digitized signals from constituent sensors are especially transferred by wireless (radio) information system to control centre (receive unit) where data are processed and evaluated. Results of evaluated information are given to operator which determines next progress.

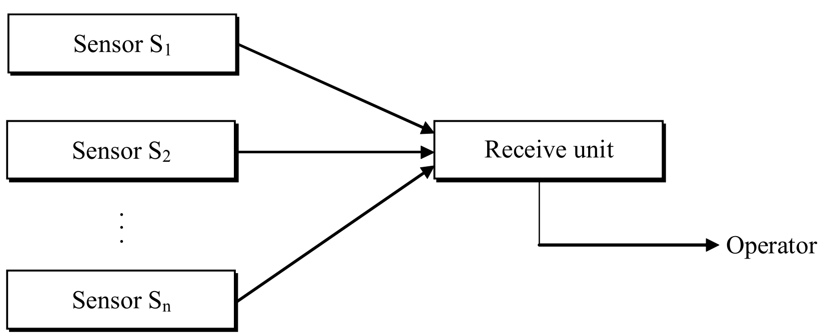

Fig. 1 Block diagram of UGMS

Fig. 2 shows basic dividing of UGMS sensors for reconnaissance and guarding of the area of interest [2]. Emphasized types of sensors are used the most often by UGMS. Therefore, they are (except piezo cable) implemented in practical part of the project.

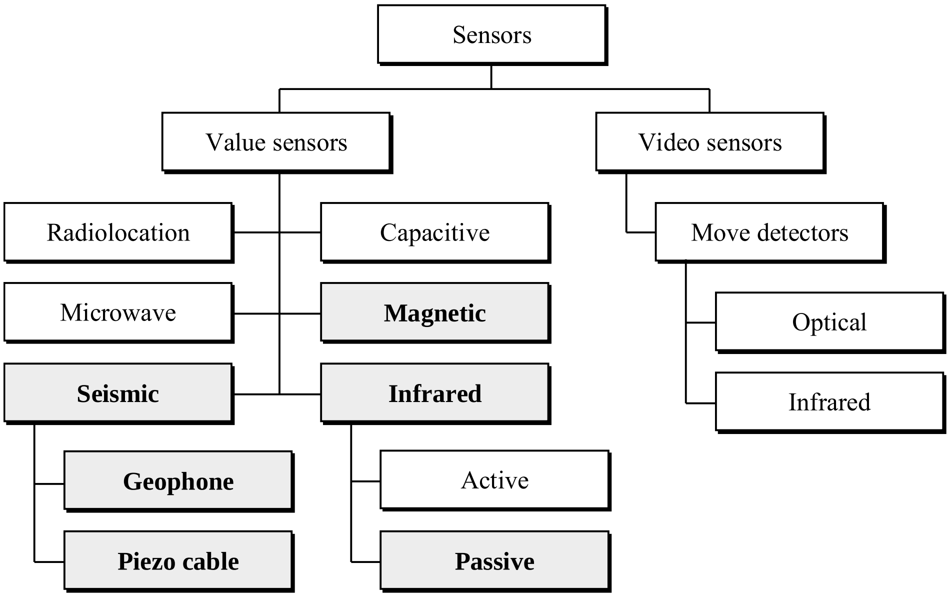

Fig. 2 Basic UGMS sensors dividing for guarding of the area of interest

There are many different types of UGMS in the world, for example European CLASSIC (Covert Local Area Sensor System for Intruder Classification) using in the armies of NATO alliance or American REMBASS (Remotely Monitored Battlefield Sensor System).

Among others used monitoring systems are counted for example OASIS (Optical Acoustic Satcom Integrated Sensors), TRSS (Tactical Remote Sensor System) or MIDS (Mini Intrusion Detection System). Own monitoring system is researched also in the Department of radiolocation at University of Defence in Brno. Fig. 3 graphically shows basic working scheme of CLASSIC system.

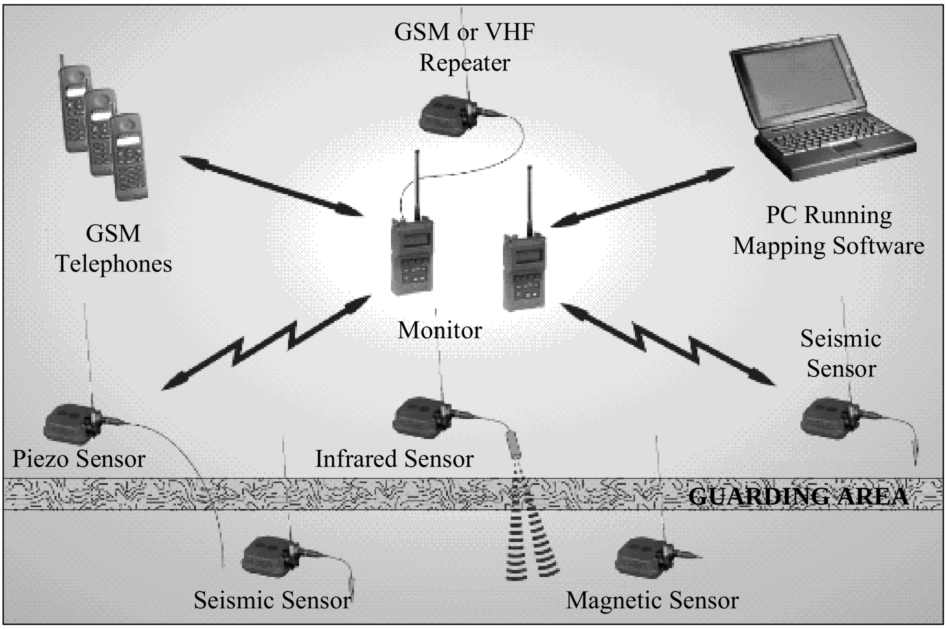

Fig. 3 Working scheme of CLASSIC system

2.2. Digitized geographical data

In the Army of the Czech Republic at least two formats of digitized geographical data are accessible:

- Maps from Military Geographical and Hydrometeorological Institute in Dobruška.
- Maps from combat simulator OTBSAF running at University of Defence in Brno.

The first variant is used for problem solution of sensor positioning. To these maps is accessible very detailed documentation, for example [5].

Maps use plane right-angled coordinate system WGS 84/UTM (World Geodetic System 1984 / Universal Transverse Mercator). It is standard cartographic system used in armies of NATO alliance.

Complete digitized map is composed of following layers:

- Digital landscape model.
- Digital terrain model.
- Soil database.
- Satellite pictures.

2.3. Used methods for UGMS sensors positioning

In present days there are high quality UGMS systems, constituent sensors are positioned in the area of interest by operators. Quality of position depends on intuition and experience of operator, so important role is played by human factor. Among other varying ways of sensor positions are counted traditional methods.

In studied literature there is usually enumerated following general dividing of traditional methods [3].

- Combinatorial methods.
- Methods of operational research.
- Heuristic methods.

Traditional methods are based on knowledge of objective function. Objective function precisely describes the problem and determines optimization criterion. Problem solution consists in location of maximum (or minimum) of given objective function. However, there are problems, in which objective function is not possible to express (or it is too difficult), eventually this function isn't suitable for solving by traditional methods. So, similar problems are not possible to be solved via traditional methods.

Among problems with unknown objective function it is possible to count problem of UGMS sensors position. Diversity and complexity of digitized terrain prevent expression of objective function. The only way exists in considerable simplification of digitized terrain. Overmuch simplification can signify serious inaccuracies. The problem condition is creation of precise model which is possible to apply to real environment. When the simplification is too big this condition isn't fulfilled.

So, problem is necessary to solve by methods without the need of total knowledge of objective function. Among these methods are counted stochastic search methods which are popular in present days. In practice, it is possible to find many problems solved by these methods. Among solved application are also positioning problems (for example position problem of electronic components on printed circuit [4]). Problem of sensor position is suitable for solution via stochastic search methods.

3. Problem solution of sensors position

The main aim of the project is finding and checking of generally practically usable working processes and methods which ensure optimal position of sensors of unattended ground monitoring system in the digitized area of interest.

Procedure for fulfilling this aim is following:

1. Analysis of principles and design of problem solution of sensors position.
2. Creation of generally mathematical models for three types of sensors based on seismic, infrared and magnetic physical principles.
3. Application of optimization methods for problem solution of sensors position.
   - Analysis of parameters and possibilities of optimization methods and their implementation.
   - Suitable setting of parameters values of implemented optimization methods.
   - Evaluation and mutual comparison of optimization methods.
4. Specification of other problems.
   - Selection of suitable set of sensors for solution of specific task.
   - Description of principles and possibilities at detection, identification and localization of interest objects.
   - Analysis of situation at dynamic changing of parameters.
5. Simulation checking of gained theoretical pieces of knowledge and conclusions.

3.1. Principles analysis and design of problem solution

Chapter discusses basic principles and processes for problem solution of position optimization of UGMS sensors in the DAI.

Digitized area of interest

First operation before problem solution is delimiting of the area of interest in digitized map. Area of interest exactly borders area in map in which it is necessary to optimal position of UGMS sensors.

All objects of digitized map (object of digital landscape model, digital terrain model and soil database), lying in the interest area, are becoming component of models of constituent UGMS sensors and influence problem solution.

Problem of optimization of sensors position

Problem solution includes following steps:

1. Loading of digitized geographical data.
2. Problem assignment and delimitation of the area of interest.
3. Application of mathematical models of sensors.
4. Launching of optimization method.
5. Evaluation of solution results.

Fundamental prerequisite for a problem solution via optimization methods consists in calculating the total coverage of the DAI by the monitoring system (or more precisely by its sensors positioned in the area of interest). Coverage calculating is carried out on the basis of mathematical models of sensors.

Each UGMS sensor is described by a general mathematical model. All parameters which might influence the sensor function are included in this model. Resulting from this model, the area monitored by the sensor for particular parameters is created. Generally, monitored area is expressed by formula (1).

$$O = f(x, y, p, d, l, m, t), \qquad (1)$$

where O is area monitored by a sensor,
x and y are positions coordinates of a sensor,
p are parameters and characteristics of a sensor,
d is a problem assignment,
l is terrain influence on monitoring,
m is influence of weather conditions,
t is time of monitoring.

Fig. 4 graphically shows example of an area monitored by sensor. Area is created by a sensor model application based on formula (1). Monitored area is possible to count as area where interest objects will be monitored certainly. Figure shows the monitored area for concrete values of parameters.

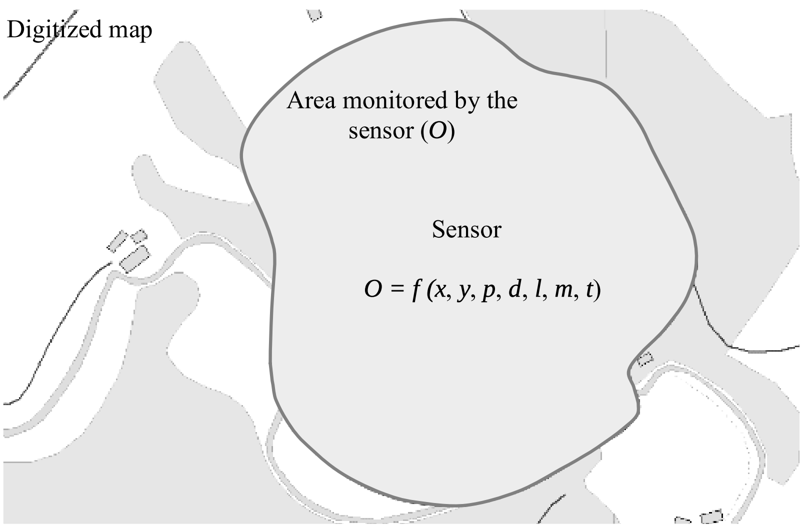

Fig. 4 Illustration of the area monitored by the sensor

Monitored area is determined for each positioned UGMS sensor. In order to express the total coverage of the DAI by monitoring system, mathematical operators of a set theory are used. UGMS is composed of sensors S_1, S_2, ..., S_n, where n is a total number of sensors. Component sensors monitor areas O_1, O_2, ..., O_n. Covering the area of interest P follows the unification of areas O_1 to O_n according to formula (2).

$$P = O_1 \cup O_2 \cup \ldots \cup O_n \tag{2}$$

Coverage coefficient is defined as a proportion of the DAI coverage to its total surface according to formula (3). Coverage coefficient gets the value from 0 to 1 and it represents coverage rate of the DAI. Coverage rate is a basic parameter which selected optimization methods work with.

$$k = \frac{P}{C}, \tag{3}$$

where k is coverage coefficient of the DAI,
P is coverage of the DAI,
C is total surface of the DAI.

Coverage of the DAI is calculated by vector geometry. The areas monitored by constituent sensors in the area of interest are possible to account the geometrical objects (see Fig. 4). By unification of these objects is created one object. Surface of this object corresponds to total coverage of the DAI by monitoring system.

Effective way of coverage calculation is rasterizing of the DAI. The area is divided to equally sized squares. Sensors check the ability to monitor interested objects on constituent squares. Checking proceeds only in one point of square. It is assumed that the sensor is able (or isn't able) to monitor objects in all area of checked square.

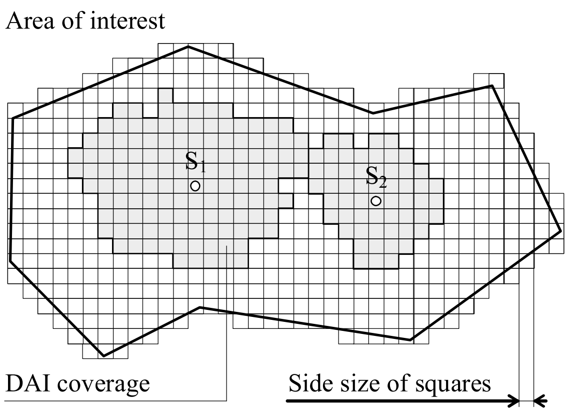

Fig. 5 Coverage of a rasterized area of interest by two sensors

Fig. 5 shows this principle graphically. White parts of the area of interest represent constituent rasterizing squares. Gray colour fills up the area monitored by two sensors S_1 and S_2. Side size of square determines a precision of solution. The less side means more total number of squares (so more precision) but the less speed of optimization process.

Total DAI coverage is given by number of monitored squares. Coverage coefficient is possible to calculate according formula (3) analogically. Parameter P from formula represents number of squares monitored by UGMS sensors, parameter C represent total number of rasterized squares in the area of interest.

Application of optimization methods to sensors position problem

Position of each UGMS sensor in the area is expressed by a set of variables which share the resulting coverage of the DAI. Position coordinates x and y (see formula 1) are always a part of these variables, eventually there are some other variables (depending on the type of sensor, e.g. the angle of sensor or position height of sensor over the terrain).

Problem of sensor position is switched to the problem of extreme searching in the function of more variables. Each variable at component UGMS sensors represents one variable of the optimized function. For example, optimizing the position of 6 sensors (the position of these sensors in the area is expressed only by position coordinates – i.e., two variables for each sensor) it is necessary to optimize the function of 12 variables.

Objective function of a problem can be interpreted as a function of coverage of the DAI according to formula (2). Component areas monitored by sensors are expressed by formula (4).

$$O_i = f(x_i, y_i), \quad (4)$$

where O_i is an area monitored by i-th UGMS sensor,
x_i, y_i position coordinates of i-th sensor in the area.

However, formula (4) is valid only for those types of sensors in which there are no other position variables. Generally, the area monitored by a sensor is described by formula (5). In this formula there are position coordinates x_i and y_i and new variables a_i, b_i, c_i etc. These additional variables are also concerned in position of sensor in the area. Each type of sensor has an exactly determined number and sense of additional variables.

$$O_i = f(x_i, y_i, a_i, b_i, c_i, \ldots), \quad (5)$$

Total coverage of the DAI is expressed by formula (2), particularly it is expressed by formula (6).

$$P = f(x, y, a, b, c, ...), \quad (6)$$

Parameters x, y, a, b, c do not express only variables of one sensor. It is a set of variables of all positioned UGMS sensors. Composition of a set of variables x and y from formula (6) is expressed by formula (7). Composition of a set of variables a, b and c can be expressed analogically.

$$x = \{x_1, x_2, ..., x_n\}, y = \{y_1, y_2, ..., y_n\}, \quad (7)$$

where x, y are sets of position coordinates of all positioned UGMS sensors,
x_1, y_1, x_2, y_2 to x_n, y_n are position coordinates of positioned UGMS sensors,
n is a total number of positioned UGMS sensors.

Between formulas (1) and (5) (both express the area monitored by sensor) there is an evident difference. In formula (1) there are parameters p, d, l, m and t, which are missing in formula (5). These parameters also influence the size and shape of the area monitored by a sensor; however, in a given problem they are static. They are set before optimization according to the situation, they do not change during the whole time of the problem optimization, and hence they can be eliminated from formula (5). Values of these static parameters are included in the whole calculation of the areas monitored by particular UGMS sensors.

3.2. Sensors models

In the project there are designed and realized models for following types of sensors:

- Seismic sensor.
- Infrared sensor.
- Magnetic sensor.

The purpose of model is simplification of the reality. However, the results of the model application must correspond to the modelled object in reality. Into sensor model must be included all parameters influencing its function principally. The fundamental categories of parameters are presented in formula (1). Project deals in detail with design and construction of above sensors models and analysis of influence of all the fundamental categories of parameters.

Each UGMS sensor has many properties and characteristics influencing its function but it is necessary to put into model only some of them. The properties and characteristics of sensor are: type of sensor, monitoring range, precision, reliability, capacity of feed source, adaptation, diagnostic possibilities, intelligent control possibilities, malfunction resistance, mutual cooperation possibilities, possibilities of detection, identification and localization etc.

Problem assignment has high influence on sensor function, it is necessary to put its parameters to models. Among the problem assignment parameters are counted types of monitored interest objects (persons, wheeled vehicles, tracked vehicles, air targets), ways of interest object monitoring (detection, identification, localization), values of meteorological conditions or delimitation of the area of interest.

Among significant parameters of sensor models are counted terrain objects. Influence on sensor function might have objects as forests, vegetations, water flows and areas, communications, railway lines, buildings and other industrial objects, pipelines, energetic cables, type and sort of soil, terrain relief etc. Among important meteorological conditions are counted temperature, atmospheric pressure, humidity, cloud amount, direction and force of wind, visibility, precipitation and snowfall etc.

State of feed source is influenced by working time of a sensor. One of the model parameters is also monitoring time because feed source discharges. It might become to decreasing of the area monitored by sensor. However, it is necessary to say that the monitored area is usually changed suddenly.

In practice part of the project are set realized models so that they represent sensors of four real monitoring systems: CLASSIC, REMBASS, OASIS and UGMS in University of Defence in Brno.

3.3. Optimization methods

For problem solution of position optimization of UGMS sensors in the DAI were implemented following optimization methods:

- Random search.
- Simulated annealing.
- Genetic algorithm.
- SOMA algorithm.
- Full set of solutions.

The first four above mentioned methods belong to stochastic search methods category, the last one comes under combinatorial methods. Search methods are characterized by searching of state space. State space is set of all solutions of concretely given problem. Solution is one of many variants of sensors position in the DAI.

The purpose of optimization methods is finding of optimal solution in set of all solutions. Basis of function of chosen methods is evaluation of quality of any solution from set. Quality in sensors position problem is rate of interest area coverage. Function evaluating solution quality is called fitness function which appears from objective function in formula (6).

Fitness function evaluates each solution by non-negative real numbers proportional to solution quality (high value of fitness function means superior solution). It is mapping from set of all solutions to set of non-negative real numbers. This mapping is expressed by formula (8). Relationship between objective and fitness function depends on used optimization method and set parameters (for example on modification way of selection pressure).

$$f(x): X \rightarrow \Re^{+}, \tag{8}$$

where x is vector of variables representing one solution,
$f(x)$ is fitness function,
X is set of all solutions,
$\Re^{+}$ is set of all non-negative real numbers.

In project, there are described chosen optimization methods in detail. It deals with their centre, parameters and possibilities. A part of project is checking of functionality of chosen optimization methods, empirical setting of their parameters values and their evaluation and mutual comparison.

In Fig. 6, 7 and 8 are introduced parameters and features of three optimization methods: simulated annealing, SOMA algorithm and genetic algorithm. All shown parameters and features are implemented to the software application.

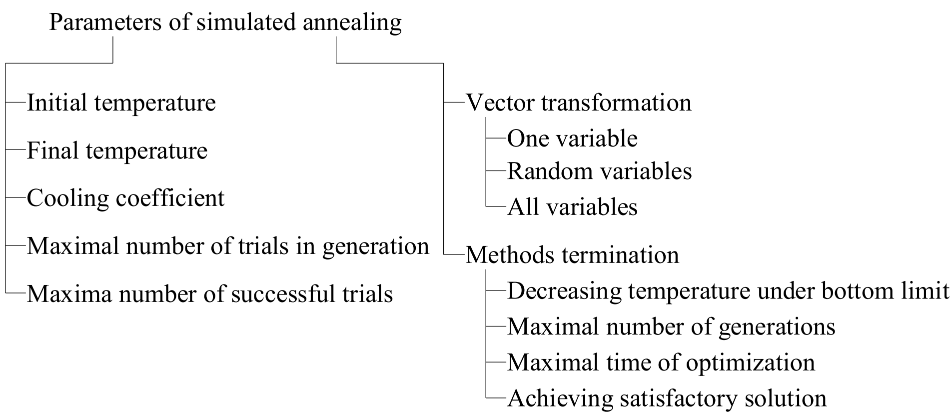

Fig. 6 Summary of implemented parameter of simulated annealing

Parameters of genetic algortihm

- Population size
- Representation of individuals
  - Binary
    - Natural binary code
    - Gray code
  - Real
- Natural selection
  - Selection coefficient
  - Modification of selection pressure
    - None
    - Linear
    - Non-linear
  - Method of natural selection
    - Roulette wheel selection
    - Stochastic universal sampling
    - Remainder stochastic sampling
      - With replacement
      - Without replacement
    - Tournament selection
    - Elitist trimming
    - Rank selection
    - Random selection
- Population reinsertion
  - Elitist strategy
  - Generation gap
  - Reinsertion strategy
    - Based on quality
    - Based on age
    - Random reinsertion
- Recombination operators
  - Crossover probability
  - Mutation probability
  - Binary crossover
    - Single-point crossover
    - Multi-point crossover
    - Uniform crossover
  - Real crossover
    - Intermediate crossover
    - Linear crossover
    - Linear crossover with mutation
    - Discrete crossover
  - Binary mutation
  - Real mutation
    - Incremental mutation
    - Discrete mutation
- Algorithm termination
  - Maximal number of generations
  - Maximal time of optimization
  - Achieving satisfactory solution
  - Number of generation without solution improvement
  - Ordering parameter
- Multiple populations
  - Number of populations
  - Migration rate
  - Selection of migrated individuals
    - Random selection
    - Based on quality selection
  - Migration topology
    - Ring topology
    - Neighbourhood topology
    - Unrestricted topology

Fig. 7 Summary of implemented parameters of genetic algorithm

Parameters of SOMA algorithm

- Population size
- Steps size
  - Step coefficient
  - Minimal number of steps
  - Maximal number of steps
  - Step coefficient behind target
  - Path deflection
- Algorithm termination
  - Maximal number of generations
  - Maximal time of optimization
  - Achieving satisfactory solution
  - Difference between the best and the worse solution
- Algorithm variants
  - All-To-One
  - All-To-All
  - All-To-One-Rand
  - All-To-One-Fitness
  - All-To-All-Adaptive
- Multiple populations
  - Number of populations
  - Migration rate
  - Migration topology
    - Ring topology
    - Neighbourhood topology
    - Unrestricted topology

Fig. 8 Summary of implemented parameters of SOMA algorithm

3.4. Specification of other project problems

The project also deals with the following three additional problems:

- The selection of a suitable set of sensors for concrete problem solution.
- Possibilities of detection, identification and localization of the objects.
- Situation analysis when dynamic parameters are changed.

The first additional problem solves the selection of a set of sensors which are suitable for monitoring of the interest objects in concrete assignment problem. The second additional problem deals with the principles and possibilities at detection, identification and localization of the interest objects. The last additional problem analyses the situation of dynamic changes of parameters and discusses two different points of view: aerial and casual blackout of sensors and the influence on the total interest area coverage.

3.5. Simulation checking of gained theoretical pieces of knowledge

Practical result is open software application. Simulation checking of gained theoretical pieces of knowledge and conclusions were processed in this application through suitable testing experiments and solving of optimization problems.

Testing experiments served for function checking of implemented optimization methods and for empirical setting of values of their parameters. On the project CD is saved a total of 544 protocols about progresses of optimization of testing experiments with total time of optimization more than 103 hours.

Optimization problems cover the basic typical situations arising in a real environment. On 12 individual problems there were processed a total of 49 optimization experiments with total time of optimization more than 161 hours. Analysis of protocols with solution of optimization problems is base for evaluation and mutual comparison of constituent optimization methods.

The most successful method (so method giving the best results in problem of sensors position) is simulated annealing. Good results are possible to reach with genetic algorithm and SOMA algorithm. Random search and full set of solutions are almost unusable (random search is characterized by low quality of found solution, creation of full set of solution needs unacceptably long time for optimization).

4. Results and contribution of the project

The result of the project is a compact materials dealing with complex problems of optimization of UGMS sensors position in the DAI.

4.1. Theoretical results

Theoretical results of the project are following:

1. Creation of analytic material relating to the monitoring system problems.
2. Design of problem solution of monitoring system positioning.
3. Derivation and proposal of construction of following mathematical models:
   - § Model of seismic sensor.
   - § Model of infrared sensor.
   - § Model of magnetic sensor.
4. Analysis and checking of working principles, possibilities and parameters of the following optimization methods:
   - § Random search.
   - § Simulated annealing.
   - § Genetic algorithm.
   - § SOMA algorithm.
   - § Full set of solutions.
5. Design of chosen testing experiments and optimization methods.
6. Design of methodology at selection of suitable set of sensors.
7. Description of the principles and possibilities at detection, identification and localization of the object of interest.

8. Analysis of situation at dynamic changes of parameters.
9. Design of selected parameter values of optimization methods based on results acquired from the processed testing experiments, analysis of influence of method parameters on reached results, evaluation of usableness and applicability of constituent optimization methods.
10. Discussion of results reached and their evaluation and comparison.

4.2. Practical results

Practical results of the project are following:

1. Creation of an open software application with the following features:
   - Interactive visualization of digitized geographical data.
   - Support of plane and geodetic coordinate system.
   - Implementation of designed construction of constituent sensors models.
   - Support of models of seismic, infrared and magnetic sensors for four monitoring systems (CLASSIC, REMBASS, OASIS, UO).
   - Easy editing of the values of the sensor parameters.
   - Implementation of five optimization methods with support of all parameters derived in theoretical part of the project.
   - Saving of detailed protocols with optimization progress.
   - Implementation of parameters facing the dynamic changes.
2. Realizing and evaluation of a few hundred testing experiments in order to check functionality of optimization methods and the influence of their parameters on reached results.
3. Realizing and evaluation of 12 optimization problems in order to evaluate and compare optimization methods, statistic documentation of reached results.

4.3. Contribution of the project

Project deals with problems which are impossible to find in common materials. In electronic and printed form it is possible to get many present treatises dealing with architecture, construction, characteristics and features of monitoring systems. The author hasn’t found any material dealing with problems of monitoring system sensors position.

Certainly, all modern armies and specialized civil corporations throughout the world deal with problems of sensors position. However, all reached information is strictly protected in order for keep safe or for commercial interests.

The project contribution consists especially in detailed analysis of sensors position problem, complex design of problem solution including creation of models for sensors based on seismic, infrared and magnetic physical principle, implementation of five optimization methods and practical checking and evaluation of theoretically reached pieces of information on real geographical data. The project purveys new available pieces of knowledge and conclusions for practice in the problems of monitoring systems position.

The project approaches to solution of sensors position by a non-traditional way. It replaces commonly used methods by stochastic search algorithms. Optimization methods are implemented with many possibilities and parameters which are thoroughly checked and evaluated in practice part. Project contribution consists also in using reached knowledge and contributions to other similar problems.

Practical project contribution consists in creation of software application covering solution of a few hundred individual problems. In application it is possible to practically test and check theoretically reached pieces of knowledge. Application source code is open and their part (for example implemented optimization methods) is possible to use in other applications.

5. Conclusion

Project is contribution to solution of selected actual problems of the digitized area of interest. It deals with processing and analysis of digitized geographical data and processes the problems of unattended ground monitoring systems and their positioning. Problem of sensor positions is solved by stochastic search algorithms instead of commonly used traditional methods.

The topic of the project is relatively wide, so it is understandable that it is impossible to span all solved problems in one project by absolute complete way. Extensiveness of solved topic corresponds to project range – project is necessary to understand as contribution to problems of unattended ground monitoring systems and their positioning in the digitized area of interest. Project doesn't cover the monitoring systems in the light of detailed description of their architecture and physical principles.

A major part of the theoretically derived and described algorithms and procedures for problem solution were implemented to developed software application. Optimization methods were implemented including all properties and parameters described in the project and it was checked by their functionality in practice.

Selected approach to the solution of these problems wasn't possible up to the last decades of the 20^{th} century because same indispensable individual steps of problem solution (especially application of sensors models to digitized area of interest and evaluation of constituent potential solutions) are exceedingly computationally hard. Problem is possible to solve by described procedures on the present when the powerful digital computation systems are available.

The project brings new component pieces of knowledge and conclusions which can be base for the next research in this area. Reached results can be of use to the Armed Forces of the Czech Republic (guarding of the areas of interest, support of combat activity or fighting against the terrorism) but also in civilian sphere (for example in security services) because literary sources dealing with similar problems aren't available.

The project opens (in author's opinion) many possibilities and perspectives of next progression in future. Direction of next research could aim to some other theoretical, practical and organizational areas. From the theoretical area it is possible to continue in design and implementation of the same other optimization methods (for example Bayesian evolutionary algorithm), analysis other procedures and possibilities of already realized methods or creation of models for sensors based on other physical principles (acoustic sensor, chemical sensor, thermal sensor etc).

In the practical area it is necessary to check some component theoretically derived piece of knowledge, especially it is necessary to check functionality of sensor models in the real environment and accomplish their possible actualization and supplement. Also it is necessary to accomplish a thorough functional and exercise testing of developed software application, continuously update it and fulfil some other functions and possibilities (for example compilation of complete application help, insertion the functions for manual sensor positioning, allowing to save and load solved optimization problems including reached results).

In the organization area it could be possible to solve questions according to accessing and utilization of reached pieces of knowledge in Armed Forces of the Czech Republic. For starting up the system on some specialization workplaces (for example in Centre of Simulation and Trainer Technology at University of Defence in Brno) it is necessary to compile exact organization plan including implementation plan, operation and personal activities support, training of system users in the theoretical and the practical sphere, launching these problems to lessons, possibly starting up special seminars.

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Introduction of Author:

STODOLA Petr, Dipl. Eng., Ph.D., Scientific and pedagogic worker, University of Defence, Faculty of Economics and Management, Department of Military Management and Tactics.