PROBLEM SOLUTION OF MONITORING SYSTEMS POSITION OPTIMIZATION

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Abstract

The paper deals with principles and procedures for problem solution of unattended ground monitoring systems position optimization in the digitized area of interest. The paper follows the concept of digitized area of interest, defines problem of sensors positions optimization and suggests component steps and procedures for this problem solution via optimization methods.

Keywords

Monitoring system, sensor, area of interest, optimization method, optimization problem, position of sensors, problem solution

1. Introduction

The paper is a follow-up to the papers [1], [2], [3], [4] dealing with problems of unattended ground monitoring systems (UGMS) position in the digitized area of interest (DAI). This paper defines principles of position problem of UGMS sensors in the DAI and appoints solution process of this problem.

UGMS are defined as the heterogeneously spread ground detection systems serving guarding the interest areas or objects. UGMS are used particularly for military purposes (guarding the interest areas against entering the enemy, guarding state borders, protection against terrorism and others), but also in civilian sphere (leak detection of dangerous materials from industrial objects, fire or contamination detection). UGMS are most frequently used for military purposes: to detect and recognize persons, wheeled and tracked vehicles.

UGMS are composed of separate self-sustaining “intelligent” sensors working as the input elements of systems. Digitized signals from particular sensors are beamed generally by wireless (radio) information system to the control centre where the collected data are processed and evaluated.

2. Digitized area of interest

DAI defines area on digitized map (i.e., on digitized geographic data) where it is necessary to position UGMS sensors in an optimal way. DAI is generally defined by simple polygon (figure 1 shows examples of DAI boundaries; the DAI is bounded by black line and filled with yellow color).

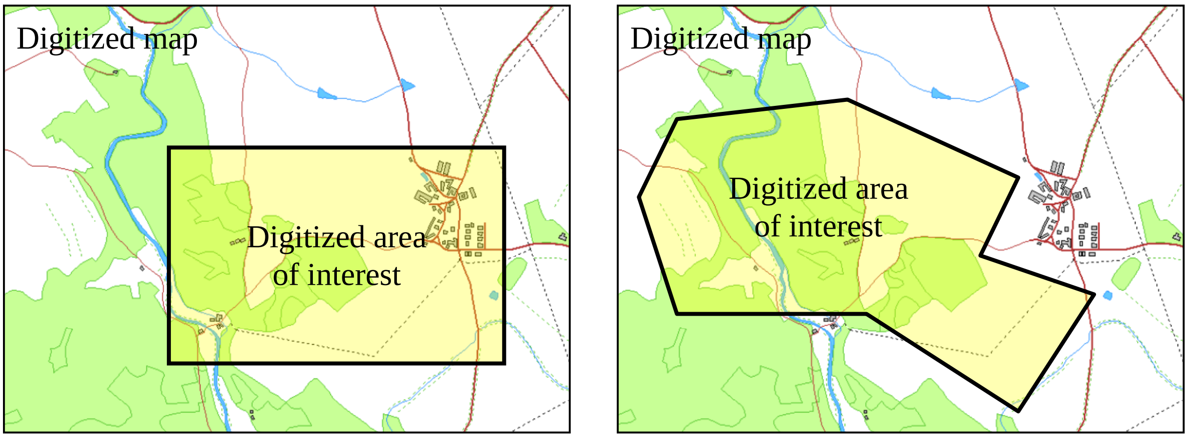

Figure 1 Examples of DAI boundaries

3. Problem of sensors position optimization

UGMS sensors are main source of topical information from the area of interest. Correct position of these sensors guarantees total monitoring of the area of interest. Purpose of this problem consists in positioning the sensors in an optimal way. The concept of “optimal way” can be considered differently. Generally it means the solution complying with problem conditions and fulfilling a particular aim. The aim covering the problem of sensors position 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.

Solution of sensors position covers the steps as follows:

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

Problem solution consists in processing digitized geographical data, application of mathematical models of sensors to this geographical data and application of implemented optimization methods.

Fundamental prerequisite for a problem solution by optimization methods consists in calculating the total coverage of the DAI. Calculation 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).

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

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.

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 (see figure 2). Monitored areas do not project off the area of interest (or more precisely the parts out of DAI are cut). Covering the area of interest P follows the unification of areas O_1 to O_n according to formula (2).

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

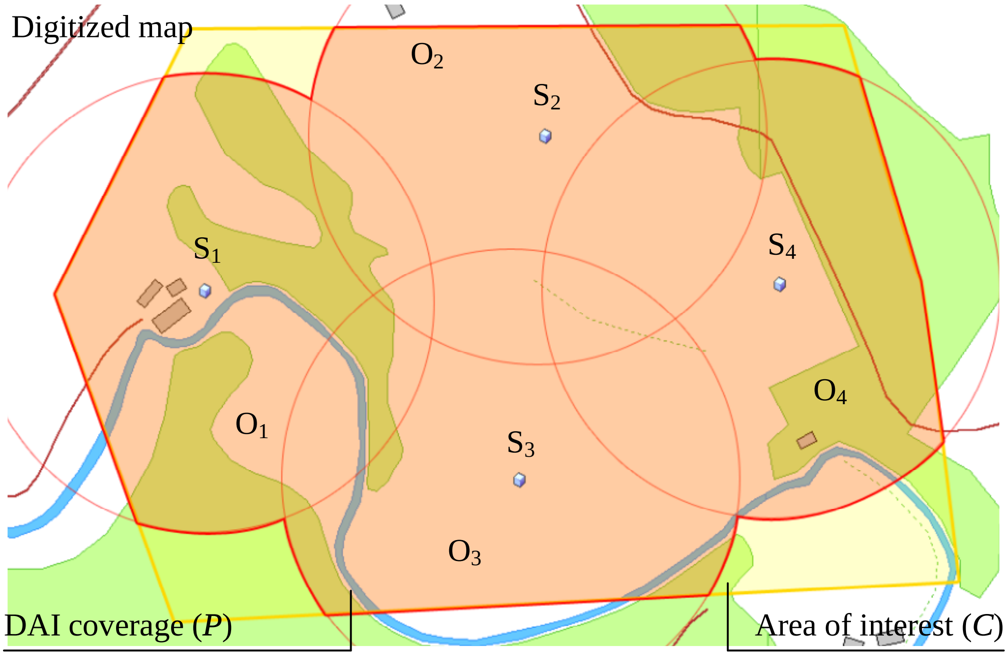

Figure 2 Example of total DAI coverage by four UGMS sensors

Coverage coefficient is defined as a proportion of DAI coverage to total surface of the DAI according to formula (3). Coverage coefficient gets the value from 0 to 1 and it represents coverage rate of the DAI (eventually quality of sensors position). 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.

4. Problem solution of sensors position optimization

Search optimization methods are used to solve UGMS sensors position problem in the DAI: these methods are characteristic through searching state space. Some appropriate optimization methods have been used: random search, simulated annealing, genetic algorithm or SOMA algorithm.

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).

$$O_i = f(x_i, y_i), \tag{4}$$

where O_i is area monitored by ***i***-th UGMS sensor,
x_i, y_i are 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. But there are types of sensors with other variables with effecting a sensor position. For example, infrared sensors (with field of sight smaller than 360°) have a new position variable – angle of sensor φ_i. Area monitored by infrared sensor is therefore expressed by formula (5).

$$O_i = f(x_i, y_i, j_i) \tag{5}$$

Generally, the area monitored by a sensor is described by formula (6). 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 exactly determined number and sense of additional variables.

$$O_i = f(x_i, y_i, a_i, b_i, c_i, ...) \tag{6}$$

Total coverage of the DAI is expressed by formula (2), particularly it is expressed by formula (7).

$$P = f(x, y, a, b, c, ...) \tag{7}$$

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 (7) is expressed by formula (8). Composition of a set of variables *a*, *b* and *c* can be expressed analogically.

$$x = \{x_1, x_2, ..., x_n\},\ y = \{y_1, y_2, ..., y_n\}, \tag{8}$$

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 constituent positioned UGMS sensors,
n is a total number of positioned UGMS sensors.

For example, if the purpose of optimization methods is a position of 3 UGMS sensors in the DAI, objective function is expressed by formula (9). Position of first two sensors in the area follows the position coordinates according to formula (4), at the third sensor there is furthermore the angle of sensor according to formula (5).

$$P = f(x_1, y_1, x_2, y_2, x_3, y_3, j_3) \tag{9}$$

Between formulas (1) and (6) (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 is missing in formula (6). 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 (6). Values of these static parameters are included in the whole calculation of the areas monitored by particular UGMS sensors.

Selected optimization methods work with whole set of possible solution of a given problem. Fundamental prerequisite for a problem solution consists in evaluating fitness (quality) of particular solutions. Fitness of each solution is given by the rate of coverage of the DAI for given position of UGMS sensors, i.e., for particular variables from formula (7).

5. Conclusion

More detailed information on the problem of position optimization of UGMS sensors in the DAI can be found particularly in [1]. This paper deals with principles and procedures of a problem solution. Some other aspects of these problems have not been solved here (for example, models of sensors or application of optimization methods and their simulation verification).

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