Application of cellular automatons and ant algorithms in avionics

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Abstract. The paper considers two algorithms for searching quasi-optimal solutions of discrete optimization problems with regard to the tasks of avionics placing. The first one solves the problem of optimal placement of devices by installation locations, the second one is for the problem of finding the shortest route between devices. Solutions are constructed using a cellular automaton and the ant colony algorithm.

1. Introduction
Development of electronics and digital computer technics has led to quick increase in the number of placing aboard a plane electronics (so-called avionics). Multitude of electronic devices requires standards of its physical arrangement and data transmission buses. In 1990-th years set of heterogeneous united electronic devices was changed for system of computers and general purpose interfaces which look like plug-in architecture of personal electronic computer. Nowadays such systems of placing aboard a plane electronics are called integrated modular avionics (IMA).

IMA devices, called modules, fulfill several functions of on-board systems simultaneously using standardized software. Peripheral devices are connected with general system of input-output interfaces. Common broadband network with high bandwidth consolidates all IMA modules. Simultaneous realization of several functions of aircraft by one module enhances the capacities of modern processors. This makes it possible to reduce the number of aircraft electronic devices and at the same time to minimize mass and cost of avionic system, and also costs for developing, production and maintenance.

Nowadays systems of IMA devices are implemented in all modern civil and military aircrafts, business jets and helicopters. The second-generation systems of IMA devices, so-called distributed integrated modular avionics (DIMA), are implemented in aircrafts of the type Boeing 787 and A350 (see the [2]).
2. Objectives
The present paper seeks to achieve two objectives of DIMA: spatial distribution of devices and identifying of peripheral cables. Software of devices’ provision identifies spatial distribution of DIMA in general structure of aircraft electronic devices. The devices are identified with locations which are limited by volume. The factor which limits process of displaying devices and its locations is set of resources required by devices and provided by locations. In addition, it is necessary to take into account the constraints of spatial distribution. This algorithm yields a scheme like represented in figure 1.

Algorithm of quasi-optimal spatial distribution of devices by location with the use of modified social potential is proposed as the same as the one adopted for modeling and simulation of swarm of agents in the [3]. The very objective of optimization is solved through the cellular automata model, this idea of using it for resource allocation was derived from the paper [4].

The peripheral cables connects peripherals to DIMA devices. This objective is being addressed under the limits on the number of cables and connections between the wires in cable routes. If two tasks which require peripherals should be segregated, it is estimated that peripheral cables also should be segregated, i.e. wires must not overlap anywhere in their routes. Identifying of peripheral cables yields segregated route for each peripheral cable. Such route is described together with all cable routes, connections and locations which it runs through. The full set of all routes must not exceed the amount of resources in each of cable routes, connections or locations, without any two routes disrupting the requirement of segregation. A search algorithm of quasi-optimal designation of cable routes is proposed as the one of ant colony seeking optimal way in graph of the same type as described in the[5].A significant characteristic of algorithm is simultaneous coexistence of several ant colonies.

3. An objective of minimization of a cable length
The idea of algorithm has been borrowed in its essence from the paper [6],where in some sense similar algorithm is applied for creation of random landscape with certain properties in order to verify a search algorithm of optimal way from the [7].
Suppose we are given an equal grid in \( \mathbb{Z}^3 \) and subset \( U \subset \mathbb{Z}^3 \). There are set of tools \( V = \{ v_i | i = 1, n \} \), which should be attributed to the grid cells \( U \). We are given for each tool \( v \in V \) list of tools \( C(v) \subset V \), which should be connected to \( v \) directly. It is necessary to place tools through the grid in a such way that the distance between all connected tools would have been minimal.

Since \( U \in \mathbb{Z}^3 \) is, generally speaking, nonconvex and even disconnected one, we define distance \( \rho \) on \( U \) as geodesic distance, i.e. distance between cells \( x \) and \( y \) is equal to length of minimal lattice path in between, and if there is no such path, then distance is assumed to be infinite.

Let’s introduce the concept of attractive-repulsive potential. Suppose for each tool \( v_k \in V \) is given a function \( \varphi_k: U \to \mathbb{R}_{\geq 0} \) and also a function \( \varphi_0: U \to \mathbb{R}_{\geq 0} \). These functions are meeting the following requirements (\( C_k \geq 0, \alpha_1 > 0 \)).

1. Suppose \( d_0(i, j, l) \) is a distance from cell \((i, j, l) \in U \) to border \( \partial U \) (suppose, \( \partial U \) is not contained in \( U \)), then \( \varphi_0(i, j, l) \) is increasing monotonically with the decreasing of \( d_0(i, j, l) \).
2. Suppose there is tool \( v_k \) in the cell \((i, j, l) \). Suppose \( d(i_1, j_1, l_1; i_2, j_2, l_2) = d_k(i_2, j_2, l_2) \) is a distance between cells \((i_1, j_1, l_1) \) and \((i_2, j_2, l_2) \). Then \( \varphi_k(i, j, l) \) can be expressed as

\[
\varphi_k(i, j, l) = \frac{c_{k1}}{d_k(i, j, l)^{\alpha_{k1}}} - \frac{c_{k2}}{d_k(i, j, l)^{\alpha_{k2}}}.
\]

We can assume that tool \( v_s \in V \) in a cell \((i, j, l) \) is influenced by attractive-repulsive potential

\[
\Phi_s(i, j, l) = \sum_{k=1}^{n} \delta_s(\varphi_k(i, j, l)),
\]

where

\[
\delta_s \circ \varphi_k = \begin{cases} 
0, s = k, \\
0, v_s \notin C(v_k), \\
1, v_s \notin C(v_k) \land s \neq k.
\end{cases}
\]

Let us set \( P(i, j, l) \) as a tool (more exactly, as a tool number) in cell \((i, j, l) \) and take \( P(i, j, l) = 0 \), if there is no tool in this cell. Let us set \( D = \{(i, j, l) | i, j, l = -1, 1\} \).

An algorithm is proposed as follows.

0. Tools from \( V \) are allocated arbitrarily in \( U \).
1. For each cell \((i, j, l) \in U \), it is given the list \( \{ \varphi_k(i, j, l) | k = 0, n \} \).
2. Cellular automaton starts its operation with following local function of transition:
   2.1. Tool \( v_s \) in cell \((i, j, l) \) finds such possible direction \( d = (d_1, d_2, d_3) \in D \) that \( \Phi_s(i + d_1, j + d_2, l + d_3) \) → max,
   2.2. If cell \((i + d_1, j + d_2, l + d_3) \) is free, then \( v_s \) moves to this cell,
   2.3. If cell \((i + d_1, j + d_2, l + d_3) \) is not free, but its tool is planning to move in cell \((i, j, l) \), then these tools change cells,
   2.4. If cell \((i + d_1, j + d_2, l + d_3) \) is not free and its tool is not planning to move in cell \((i, j, l) \), then we mark \( d \) as impossible and go to algorithm step 1.1.
3. We return to algorithm step 1.
4. If it’s been more than largest possible number of cycles or automaton has become stable, algorithm is finished.
4. Designation of cable routes
To find optimal cable route we will use algorithm of the same type as an ant colony one. Suppose \( V' \subseteq V \) is set of tools which have to be connected and hub devices. Also suppose we are given matrix \( A \) for tools from \( V' \), which need to be connected; if tools \( v_i \) and \( v_j \) have to be connected, \( a_{ij} = 1 \), otherwise \( a_{ij} = 0 \). Also suppose we are given matrix \( B \); if tools \( v_i \) and \( v_j \) have to be hardware segregated, \( b_{ij} = 1 \), otherwise \( b_{ij} = 0 \). We give the list of possible communication equipment (switches) \( L(v) \) for each tool \( v \in V' \).

Let’s define a graph \( \Gamma = (V, E, \psi) \), where \( E \) is set of connections between tools, \( \psi: V \to U \) is one-to-one function of tool and location, which was linked on the previous steps, and its subgraph \( \Gamma' = (V', E', \psi') \), where points are tools from \( V' \) and switches. Every ant \( m \in K_i \) at every instant \( t \) has list \( M_i(m, t) \) of the nodes \( \Gamma' \) already visited, in which it does not come back. Ants from \( K_i \) have “eyesight” in the sense that they tend to visit such points \( v_j \), where \( a_{ij} = 1 \). Let us denote set of target points \( m \in K_i \) as \( T(t, v_j) = L(v_j) \setminus M_i(m, t) \).

Every \( v_i \in V' \) corresponds to ant colony \( K_i \), which marks edges \( \Gamma' \) by its own pheromone. The colonies can “be at enmity” with each other, so that pheromone of single ant colony is repellant for hostile one, what is necessary for segregation of the routes. To limit number of connections to one node let’s assume that pheromone, the concentration of which is greater than a certain level, begins to act as a repellant. Consequently every edge \((r, s)\) between the points \( v_i \) and \( v_j \) corresponds to ordinate vector of pheromone \( \tau_{rs}(t) = (\tau_{r1}(t), \ldots, \tau_{ns}(t)) \), \( \tau_{rs}(t) \) is a pheromone level of the colony \( K_i \) at time \( t \).

Let’s define a function of pheromone detection for an ant from the colony number \( k \)

\[
\theta_{rs}(k, t) = \begin{cases} 
\sum_{i=1}^{[V]} \tau_{rs}(t), \forall(i) & b_{ik} = 0, 0 < \sum_{i=1}^{[V]} \tau_{rs}(t) \leq m_{rs}, \\
\xi, \sum_{i=1}^{[V]} \tau_{rs}(t) = 0, & 0, \text{otherwise.}
\end{cases}
\]

Here \( \xi \) is a small random number, \( m_{rs} > 0 \) is the limit number of connections via edge \((r, s)\).

5. Conclusion
The report proposes algorithms which have made it possible to find quasi-optimal solutions of the objectives of spatial distribution of devices by location and hardware routing between these devices. In contrast to the standard algorithms of discrete optimization based on the total check, proposed methods offer suboptimal solutions which require much less computer time.

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