Multicriteria adaptation principle on example of groups of mobile robots

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Abstract. The article presents a multicriteria approach to the adaptation of groups of search, explore or research robots to unknown and volatile environment conditions. The basis of this approach is the application of multicriteria analysis both at the design stage of a group of mobile robots and at the stage of its adaptation in real-time conditions. It is proposed to maintain a variety of robots by properties and by optimality criteria in order to take into account the preferred mode of operation.

1. Introduction
In [1] we proposed a multi-criteria approach to the design of complex robotic systems capable of adapting to dynamically changing operating conditions. In this article, the general principles of multicriteria adaptation are illustrated by examples of groups of mobile robots. Such groups of robots can be used for the purpose of carrying out search, explore or research work in hard-to-reach or completely inaccessible areas. For example, in search and rescue operations in emergency situations (earthquakes, destruction of structures, fires, floods). Another example is the exploration of natural resources, the discovery of oil, gas, minerals. Mobile robots can explore the relief of the seabed, craters of volcanoes, the surfaces of other planets, high layers of the atmosphere. Such technologies of the future as "smart dust" [2], self-organizing robot swarm [3], or surgery with microscopic robots can also be regarded. Other examples of mobile micro-robots applications are military robots, secure systems, smart home, telecare systems [4, 5].

The operating conditions of the robotic system can vary greatly. The environment is characterized by different permeability, chemical composition, temperature, radiation background. The passability of robots also depends on the relief of the surfaces, the structure of the cavities. In addition to the fact that these conditions are usually hard and aggressive, they can still be heterogeneous and vary dynamically in a wide range. Moreover, in a number of problems, the possible values of environmental parameters are not known in advance. This imposes high demands on the reliability of the robots being developed.

In addition to reliability, there are other criteria for the quality and efficiency of both individual robots and the robotic system as a whole. These criteria depend on the purpose of the system and the tasks it performs. And in different periods of time the system and individual robots can solve different tasks. For example, an investigation of the whole region, moving from place to place, transporting
goods, specialized work. Performance criteria can include speed, passability, positioning accuracy, accuracy of measurements and transmitted information, and other specialized indicators.

2. Multicriteria adaptation principles
Available literature on the designing adaptive systems using the word “multicriteria” simply lists a number of criteria by which the system can be optimized. Then optimization is performed either by individual criteria independently, or the main criterion is selected, and the remaining criteria are used as constraints.

The approach we propose is to use multicriteria analysis tools both at the design stage of the system and at the stage of its adaptation to the changing environmental conditions in the real-time mode of operation.

One of the main principles of designing adaptable systems is the possibility of reconfiguring the system during its operation mode [6-7]. In the case when the designed system consists of a set of mobile robots, new opportunities for such a reconfiguration appear. In particular, one can change:
- configuration of individual robots,
- composition of a group of robots,
- common centralized control system for a group of robots (if any),
- mechanism of interaction of robots with each other.

The main principle of multicriteria adaptation is taking into account changes in preferences between optimality criteria depending on changing conditions of the system functioning [1]. And the system reconfiguration should be carried out not only in accordance with the changed parameters of the environment and the task, but also in accordance with the changed preferences.

The problem of designing a group of mobile robots provides many opportunities for implementing the main principle of multicriteria adaptation. For example, we can:
- maintain a variety of robots in terms of parameters and properties,
- divide groups of robots into subgroups by specialization,
- vary the composition of a group of robots.

These advantages can allow automatic and decentralized multicriteria adaptation of a group of robots. For these purposes, bio-inspired approaches [1], such as genetic algorithms [8] and particle swarms [9], can be used.

Thus, maintaining the diversity and heterogeneous of robots induces competition mechanisms among individual robots in order to optimize the configuration of robots. In addition to competition, collaboration mechanisms can also be used to perform common tasks by a group of robots [14-15]. For example, by executing a leader-follower scenario [1, 16].

It is important to emphasize that maintaining the diversity of robots allows the use of ideas of multicriteria adaptation at the hardware level. In particular, it concerns the idea of creating a Pareto-optimal coalition of robots at the stage of multicriteria design of the system [1].

3. Sensor networks
One of the promising areas for the development of robotics technology is the creation of sensor networks, consisting of mini-sensors exchanging information via wireless peer to peer communication [10-12]. Areas of application are security and personalization systems, smart home, telecare and others [4, 5, 10]. They can also be used for search, explore or research.

The optimality criteria of such systems are the following: density of the signal coverage; data accuracy; fault tolerance; reliability of the system, the system life span; low cost and power consumption, small size, lightweight.

In [11] the main criterion is distinguished as the life span of the entire system operation without recharging. In this case, the remaining criteria act as constraints. In particular, the complete coverage of the network must be ensured. For this, special algorithms are used to calculate this coverage, which do not require knowledge of the sensors coordinates, but use wireless signals for exchanging information between the sensors. Adaptation in [11] is regarded just as self-tuning of the sensors
location in order to provide the required level of coverage. In this case, the initial location of the nodes and the target is undefined and may change.

Within the example of sensor networks, it is possible to demonstrate the ideas of the proposed multicriteria adaptation approach. In real problems, such sensor systems must operate in different modes, in which preferences for the optimality criteria of the system can be very different. Here are some examples:

1) Security systems spend most of the time in the monitoring and waiting mode. At this time, economy and reliability are more important at a given level of coverage by a signal. But at certain points in time, the system goes into the mode of threat recognition or personalization. And then the criteria for the data quality and accuracy are brought to the forefront.

2) Search and rescue systems operate part of the time in target (victim) detection mode. In this case, the size of the coverage area by the signal, the speed and efficiency of the space investigation of the robot group are important. But when localizing the target, accuracy of data transmission and fault-tolerance become more important.

Ideas in the construction of sensor networks can be used in the design of a group of mobile robots that perform other functions than sensing. In such a system, a mini-sensor can be either an individual robot or a part of a more complex mobile robot.

4. Distributed multifunctional systems

Many works are devoted to the design of adaptive modular robots [7, 13-14]. These are complex systems, consisting of separate modules, physically connected to each other. Modules can be heterogeneous and perform various functions. Such a system can also be considered a group of robots. Among the applications of modular robots are complex manipulators, mobile robots, multifunctional systems.

As a mechanism for self-adapting the modular robot, the feedback mechanism on the sensor-actuator pair is often considered. Several approaches have been proposed in this direction based on the interaction of neighbor modules or robots, in particular multi-agent algorithms called distributed consensus [14-15]. However, such firmware adaptation mechanisms do not take into account the multicriteria nature of the problem.

In [16-17] a more complex approach to designing the architecture of a distributed system of heterogeneous robots is proposed. In addition to self-adaptation mechanisms, the concept of self-management of the system is considered. Special attention is paid to the development of software for such systems, including complex algorithms for finding solutions, as well as machine learning [17].

Such a complex approach allows us to use the ideas of multicriteria adaptation of robot groups proposed in [1], as it opens up opportunities for integrating robot software with multicriteria optimization and analysis systems. For this purpose we develop Visual Analytics Tool system [18].

5. Conclusion

The proposed ideas of multicriteria adaptation of mobile robotic systems can enhance flexibility and robustness of such systems in dynamically changing conditions. This allows to transfer part of multicriteria optimization routine from design phase to the real-time phase of system operation. So we can change configurations in accordance with changing conditions and multicriteria preferences, or even optimize some parameters on-line.

The study was financially supported by the RFBR project No. 16-29-04401.

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