Multicriteria adaptation of robotic groups to dynamically changing conditions

S Yu Misyurin¹, A P Nelyubin² and V I Ivlev²

¹National Research Nuclear University MEPhI, 31 Kashirskoe shosse, Moscow 115409, Russia
²Mechanical Engineering Research Institute RAS, 4 Malyi Kharitonievski pereulok, Moscow 101990, Russia

nelubin@gmail.com

Abstract. A new approach is proposed to design complex robotic systems composed of many robots that can operate under different conditions and perform various tasks. Bio-inspired ideas of adaptation of robotic groups are discussed.

1. Introduction

In this paper we consider the problem of designing a wide class of robotic systems composed of several or many robots that interact with each other and perform common tasks. In addition, it is assumed that the designed robotic system should operate in various environmental conditions and perform various tasks.

The examples of such systems are groups of mobile robots that are designed to explore difficult to reach areas (under water, under earth, in space, under high radiation, etc.) and to perform certain operations with objects in these areas [1]. Such technologies of the future as "smart dust" [2], self-organizing robot swarm [3], or surgery with microscopic robots can also be regarded. Another example is military robots such as drones.

The design (configuration) of a particular robot includes a specified mechanical structure, the values of the mechanical parameters and the control system of the robot. The configuration of a complex robotic system consisting of many robots includes the configuration of all robots, which in general case can differ, and the control system of the whole group of robots.

The quality of the whole robotic system is evaluated according to several criteria (indicators, performance indices). The set of these criteria of quality and the relative preference between them depend on the conditions of functioning of the robotic system and the task being performed at the moment. In some conditions, one criteria are important, in other conditions the focus is put on other criteria.

2. Multicriteria adaptation of robotic systems

One approach to designing a universal robotic system is to find compromise values of quality criteria to ensure satisfactory operation of the system in all possible conditions. However, this approach leads to the fact that the resulting system in each mode is not functioning as efficiently as possible. Universality is achieved by reducing efficiency.
More promising is the design of adaptive reconfigurable robotic systems [4-6]. Ideally, such a system reconfigures itself and changes its parameters depending on the operation conditions, so that in each mode it operates most efficiently. Reconfiguration means changing the structure and values of parameters of the mechanisms, changing the rules and parameters of control systems, changing the interaction of the robots among themselves.

In the case when all the modes of operation of the robotic system are known and there is a finite number of such modes, the reconfiguration of the system between these modes can be programmed during the design phase. To do this, one should define the best configuration of the system in each mode of operation and introduce a mechanism of changeover (toggle) between these modes. In addition to the changeover mechanism, the control system of the robotic system should have a mechanism for determining that the conditions of operation changed, and the mode to be configured. In some problems these changeover mechanisms can be organized with the involvement of the operator.

In the case when the operation conditions of the robotic system change continuously, it is hard or even not possible to provide a mechanism for a smooth changeover of a system configuration. This problem can be solved by discretization of the range of variation conditions.

The situation is more complex when not all the possible operation conditions of the robotic system are known in advance. In this case, the real-time adaptation of the system is necessary.

In this paper we propose multicriteria approach to adaptation of robotic systems. Figure 1 shows an example of evaluation of a system designs by two criteria (objective functions to be minimized). These designs were obtained during parameters optimization procedure by uniformly sampling of parameter space. Each circle corresponds to the variant of design. And solid circles correspond to Pareto optimal designs.

The best variant of design should be chosen from Pareto optimal designs. This choice depends on the relative preferences between the criteria. Usually the preferences are somehow determined and fixed on the design phase and a compromise decision is made. But these preferences depend on environmental conditions and tasks of the system which can change dynamically during the system operation. So it will be better to save an option to change system configuration in accordance with changing preferences.

3. Bio-inspired approach to adaptation of robotic groups
In this paper we propose to use a bio-inspired approach to the adaptation of group of robots to the changing conditions. Adaptation of biological species to changing environmental conditions is achieved through the maintenance of biological diversity within the population. Similarly, we can use a group of robots, differing in their configuration. Using multicriteria approach we can take Pareto optimal designs as basic configurations of robots in group. Then some subgroup of robots will be better in one conditions, and other subgroups will be more efficient in other conditions.
Robots most adapted to the current conditions are put in the forefront and do most of the work. Other robots can do the same work, or can perform helper functions. Partial reconfiguration of other robots in accordance with the parameters of the fittest robots is also possible. This will increase the number of robots in the main leading group and increase the efficiency of the entire system. However, there must be diversity of configurations of robots in the population.

Changing of conditions enables the mechanism of reconfiguration of the entire robotic system. This moment can be detected by the fact that a new group of robots starts to work more efficient than the previously leading group. When this occurs, the leading group is changed. The advantage of this reconfiguration mechanism is that it can be carried out automatically without operator intervention. In addition, this process of adaptation can happen fairly smoothly if there is sufficient diversity in the population of robots. This diversity also can be maintained by regular random changes of design parameters of the individual robots, similar to the mutation of living organisms. This means that partial optimization of robotic systems can be made on-line in new and unknown conditions. We can apply here ideas from various global optimization techniques such as Genetic Algorithms [7] or Particle Swarm Optimization [8].

In addition to the change of environmental conditions, the tasks performed by a robotic system can also be changed. Moreover, multiple tasks can be performed simultaneously. This is achieved through various specializations of the robots in the system. It also can be given a counterpart of living systems – specialization in populations of ants or bees. In the case of the specialization, the approach described above with the change of leading subgroups of robots can also be used. However, the change of specialization of individual robot may require more radical rebuild of its configuration than adaptation to the changing conditions.

4. Conclusion

The proposed ideas of multicriteria adaptation of robotic systems and groups can enhance flexibility and robustness of such systems in dynamically changing conditions. For these purposes reconfigurable robots and their groups are better than fixed. This allows to transfer part of 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.

References

[1] Yu C, Nagpal R 2010 A Self-Adaptive Framework for Modular Robots in Dynamic Environments: Theory and Applications Int. Journal of Robotics Research 30 1015–36
[2] Warneke B, Last M Liebowitz B and Pister K S J 2001 Smart Dust: Communicating with a Cubic-Millimeter Computer 34 44–51
[3] Rubenstein M, Cornejo A and Nagpal R 2014 Programmable self-assembly in a thousand-robot swarm Science 345 795–99
[4] Yim M, Shen W, Salemi B, Rus D, Moll M, Lipson H, Klavins E and Chirikjian G S 2007 Modular Self-Reconfigurable Robot Systems IEEE Robotics & Automation Magazine pp 43–52
[5] Christoforou E G, Muller A, Phocas M C, Matheou M and Arnos S 2015 Design and Control Concept for Reconfigurable Architecture J. of Mechanical Design 137 042302
[6] Suzuki Y, Inou N, Kimura H and Koseki M 2006 Reconfigurable group robots adaptively transforming a mechanical structure Proc. of the 2006 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (Beijing, China) pp 2200–2205
[7] Mitchell M 1996 An Introduction to Genetic Algorithms (Cambridge, MA: MIT Press)
[8] Poli R, Kennedy J and Blackwell T 2007 Particle Swarm Optimization: An Overview Swarm Intelligence 1 33–57