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Multicriteria Search for Close to Optimal Configurations of Modular Robots for Cargo Transportation.

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SUMMARY

- Our method of searching for the best configurations of modular robots in unknown operating conditions can significantly reduce the number of robot performance tests.
- It is based on multicriteria analysis and the criteria importance theory.

INTRODUCTION

Transportation of goods for various purposes with the help of mobile robots can be used in the construction industry, during rescue or military operations, when working in an extreme environment. Modular reconfigurable and self-reconfigurable robots, which can change not only individual parameters, but also the mechanical structure, are widely studied and seem to be the most promising direction.

Due to the complexity of calculating performance index in real conditions, we need to reduce the required number of tests. In this sense, the methods of multicriteria analysis based on the criteria importance theory are effective, allowing to significantly reduce the search area for the best solutions and to find close to optimal solutions.

This work is a continuation of the study Misyurin, S.Yu., Nelyubin, A.P.: Multicriteria search for preferred configurations of modular robots for cargo transportation. Procedia Computer Science 213, 623–630 (2022).

APPROACH

Consider a simple simulation model that allows us to calculate the efficiency of cargo transportation by modular robots depending on various terrain conditions and various characteristics of robots. The product of the total number of modules and the transportation time is used as a performance index of the robot configuration:

$$f_L(y) = \frac{1}{y_5+4}\left(\frac{400-L_1-L_2}{y_1+4}+\frac{L_3+0.5L_2+20y_5+40}{y_2+4}+\frac{L_1+0.5L_3+20y_5+40}{y_3+4}+\frac{L_4+0.5L_2+20y_5+40}{y_4+4}\right)$$

Here, to describe the terrain, we use a vector of 4 parameters $L = (L_1, L_2, L_3, L_4)$, which take integer values from 0 to 100: L_1 is the number and complexity of obstacles; L_2 is the height differences; L_3 is the longitudinal slopes of the surface; L_4 is the complexity of the surface.

The robot configuration is determined by the number and composition of the modules, as well as additional control settings. Each configuration has the vector of characteristics $y = (y_1, y_2, y_3, y_4, y_5)$: y_1 is the maximum developed speed; y_2 is stability; y_3 is maneuverability; y_4 is passability; y_5 is the specific load capacity per one module. For each characteristic, robots are rated on an 8-point scale: the higher the score, the better.

METHODS

The optimization problem: for given terrain parameters L, find a feasible robot configuration with a vector estimate y^* that provides the minimum value of the function $f_L(y^*)$.

Instead of this, we consider the multicriteria problem of choosing the best vector score $y = (y_1, y_2, y_3, y_4, y_5)$, from a finite feasible set Y, using the preference information about the relative importance of the 5 criteria (robots characteristics).

The preferences depends on given terrain parameters L. To evaluate information about the relative importance of the criteria for each vector L, we calculate the performance indices for the 6 reference robots. To evaluate information about changes in preferences along the criteria scale, we calculate performance indices for another 12-13 reference robots. Using quantitative estimates of the criteria importance coefficients and values of the scale gradations, an additive objective function is constructed and with its help the best solution is selected.

RESULTS AND DISCUSSION

The feasible set Y consists of 18068 robots configurations, 790 of them are non-dominated by Pareto.

1000 numerical tests were carried out with various terrain parameters L. The optimal solutions y^* in each trial were obtained by exhaustive search among 790 estimates from the Pareto set. Among the Pareto-optimal solutions, the range of values of the performance index averaged 6.3, or 55.4% relative to the optimal value $f_L(y^*)$.

We studied the results of the proposed method for different values of its parameters. For the parameters a and b, we first use the values $a = 4$, $b = 7$, and then the values $a = 2$, $b = 4$, reducing the total number of reference vectors from 19 to 18. We also put $c = 2$.

The obtained results show that the values (4, 7, 2) of the parameters (a, b, c) on average lead to a smaller error in the search for the optimal solution than the values (2, 4, 2). In the first case, in 208 trials, the found solution y^V differed from the optimal y^*, and the average deviation was 0.0088 (0.07% relative to $f_L(y^*)$). In the second case, in 466 trials, the found solution differed from the optimal one, and the average deviation was 0.0279 (0.24%). This advantage on average can be explained by the fact that for the larger scores a and b, the reference vectors are closer to the Pareto set and this allows one to more accurately estimate preferences in this area.

In both cases, the deviations from the optimal solution turned out to be quite small, especially compared to the range of 6.3 (55.4%) of the performance index values among the Pareto-optimal solutions. This confirms the high efficiency of the proposed method, at least on the considered simple simulation model.

The final deviations of the objective function are also of practical interest. On average, they turned out to be equal to 0.0007 and 0.0015, respectively. When optimizing the value function, you can set a certain amount of error ε and choose a set of vector scores. This guarantees the inclusion of the optimal vector estimate y^* in the selected set.

CONCLUSIONS

1. A numerical experiment with a simple simulation model was carried out under 1000 different terrain conditions.
2. The effectiveness of the proposed method is confirmed by the small size of the deviations of the solutions found from the optimal ones.
3. The presented results of the computational experiment are also of theoretical interest from the point of view of evaluating the effectiveness of the criteria importance theory decision rules.