

Adaptive control methods

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SEPARABLE PROGRAMMING METHOD FOR SOLVING MULTI-DIMENSIONAL PROBLEMS OF OPTIMIZING THE PARAMETERS OF LASER INFORMATION MEASUREMENT SYSTEMS

The solution of optimization problems of laser information-measuring systems and their information and measurement channels, including functional elements for multiplicative signals, structures and technical parameters on a vector of quality indicators presented in tactical-technical requirements using expenditure indicators, is one from the main components of the theory of construction of such systems. **Purpose of the article.** Development of a universal method for solving multidimensional problems of optimization of parameters of laser information-measuring systems, no matter how it depends on the form of communication functions. The article discloses a separable programming method for optimizing laser information-measuring systems. The developed method uses the existing methods of modern mathematical programming with a separable representation of value and represents the optimum in analytical form, which allows it to "link" individual blocks of optimization problems into a common (single) solution. The method solves such problems as: multidimensionality, convergence of results, simplicity (universality), construction of exchange curves, and so on. It can be applied to any optimization problem as one-functional and multifunctional LIMS as a whole, and their information and measuring channels separately (including their functional elements). Analytical expressions for calculations are presented.

Keywords: optimization of parameters; cost; laser information measuring system; functional element; separable programming; multidimensional task.

Introduction

Formulation of the problem. The solution of optimization problems of laser information-measuring systems (LIMS) and their information and measurement channels, including functional elements for multiplicative signals, structures and technical parameters on a vector of quality indicators presented in tactical-technical requirements using expenditure indicators, is one from the main components of the theory of construction (creation) of such systems. The results of solving the general problem of optimizing LIMS can be obtained by solving the following problems: system analysis, finding links of the vector of LIMS quality indicators with a vector of technical parameters, determining fuzziness, changing consumption indicators, taking into account the multidimensionality of tasks and so on.

Thus, the development of a method that will allow us to find the optimal solution for the listed problems (tasks) is an actual scientific task.

Analysis of literature. Known methods for optimizing parameters are classified according to the forms of expressions of the objective function and communication functions into: direct search methods – dichotomy, Fibonacci numbers, etc.; linear programming methods – simplex method, the method of rotation of the matrix of coefficients, etc.; nonlinear methods – convex programming – gradient methods of the first and second orders, etc. [1 – 20]. Methods allow you to find solutions to problems of mathematical programming.

However, as a result of processing the statistics, upon receipt of the mean square regression of fuzzy cost

per parameter, the forms of the communication functions change, and, therefore, the methods of mathematical programming in solving problems.

Purpose of the article. Development of a universal method for solving multidimensional problems of optimization of parameters of LIMS, no matter how it depends on the form of communication functions.

Basic material

The main requirements that apply to methods that allow solving multidimensional problems of optimization of system parameters include the following:

- 1) versatility;
- 2) simplifying the solution of large-scale optimization problems;
- 3) the simplicity of the algorithm for solving optimization problems;
- 4) the convergence of optimization results (short time to solve optimization problems);
- 5) controllability of optimization results;
- 6) visibility (ease of checking convexity, or single-mode and other qualities);
- 7) criticality assessment (dependence of the optimum on constants and other factors);
- 8) ease of obtaining exchange curves [5].

In mathematics, the Wolf's method is well known, which is universal, but at the same time, it also has disadvantages in the linearization of all functions, which leads to a significant decrease in the iteration step for each parameter and an increase in the number of iterations [2, 20]. If the functions are not linearized, then nonlinear programming is possible, which will have the

qualities of gradient methods and will be able to adapt the step.

Most of the statements of optimization problems for LIMS parameters contain the objective function in terms of the main system indicator and the communication function, which is usually the cost (expenditure indicator). In this case, when there is a fuzzy value indicator, it is advisable to linearize only the communication function.

For a simplified solution of the problem of optimizing LIMS parameters (obtaining in an analytical form), it suffices to have a separable target function, which can be turned into a separable function of the same type. For example, when the accuracy criterion of the measuring channel LIMS depends on the maximum signal-to-noise ratio:

$$\max q(\bar{X}(\bar{Y})) = \prod_{i=1}^n X_i(Y_i), \quad (1)$$

where $q(\bar{X}(\bar{Y}))$ – signal to noise ratio; n – number of parameters, $X_i(Y_i)$ – "phase" parameter (PP), complex monotonous function of the technical parameter Y_i .

In (1) PP displays the influence of technical parameters and functions of the settings, disturbances and imperfections of the system on the signal-to-noise ratio.

Communication function $\phi(\bar{Y})$ can be of any kind, because when linearizing the cost function $C(\bar{Y})$ in circumference Y_{i0} it always becomes separable:

$$\begin{aligned} \phi(\bar{Y}) &= C_d - C(\bar{Y}) = \\ &= C_d - \sum_{i=1}^n [C_i(Y_{i0}) - C'_i(Y_{i0})(Y_i - Y_{i0})] \geq 0, \end{aligned}$$

i.e.

$$\sum_{i=1}^n [C'_i(Y_{i0})Y_i] \leq C_e, \quad (2)$$

where C_d – acceptable value;

$$C_e = C_d - \sum_{i=1}^n [C_i(Y_{i0}) + C'_i(Y_{i0})Y_{i0}].$$

The nonlinear programming problem (1), (2) can also be complex. When replacing the technical parameters on the "phase", the task becomes idle and is solved in an analytical form.

The Lagrange function of problem (1), (2) can be written as:

$$L(\bar{X}) = \prod_{i=1}^n X_i + [C_d - \lambda \sum_{i=1}^n C'_i(X_{i0})X_i].$$

We get the system of equations:

$$\forall k \in [1, n] \rightarrow \frac{\partial L}{\partial X_k} = \frac{a}{X_k} - \lambda C'_k(X_{k0}) = 0. \quad (3)$$

Since the components of the objective function are of the same type, the solution of the problem can be reduced to the form:

$$X_k = \frac{a}{\lambda C'_k(X_{k0})}. \quad (4)$$

Since the equations are identical in the system of equations (3), there is no need to solve it.

An indefinite factor can be obtained if (4) is substituted into (2), to determine λ и substitute in the formula (4). Thus, we get:

$$\begin{aligned} C'_k(X_{k0}) \frac{a}{\lambda C'_k(X_{k0})} &= C_e, \\ \lambda &= \frac{na}{C_e}, \end{aligned} \quad (5)$$

$$X_k = \frac{C_e}{nC'_k(X_{k0})}.$$

Thus, the result of determining the maximum signal-to-noise ratio can be written in the form:

$$\max q(\bar{X}) = (C_e / n)^n / \prod_{k=1}^n C'_k(X_{k0}). \quad (6)$$

At the same time, technical parameters can be obtained from inverse functions:

$$Y_k = Y_k(X_k).$$

According to the result (6), the dependence of the optimum on the ratio of the arithmetic average part to the mid-geometric part is obtained. At the same time, there is a slight increase in the complexity of the solution algorithm depending on the size of the task itself, etc.

In the same way, the problem of optimizing any application can be solved [1 – 4].

Cost is undetermined with its variability. It is reasonable to consider the cost in the period of its stability.

Cost accounting in the optimization of the parameters of the LIMS is a step to assess the quality of the system. Therefore, the cost is best taken into account based on marketing statistics.

Let us consider examples of optimization of the LIMS method, which will show the ability of the algorithm to stitch partial results of optimization of parameters.

The variance of the measurement error of the parameters of the LIMS (measuring channel) due to the random noise component of the error for the discriminators is [3, 4]:

$$\sigma_{\lambda}^2 = \frac{\Delta\lambda^2}{q} = \frac{1}{(\Delta\lambda)^{-2}q} = const / \prod_{j=1}^{n1} X_j(Y_{ji}),$$

where $\Delta\lambda$ – aperture, range of uniqueness of the estimation frame (discriminating discriminator); q – ratio of signal power to noise [2]; $X_j(Y_{ji})$ – functions of monotonic dependencies on technical parameters that affect the j -th LIMS index.

The LIMS immunity operating in continuous mode depends on the signal-to-noise ratio q , and in the case of

an information digital system with m_1 orthogonal signals, the probability of error can be written as:

$$P_{err} (average) = \sqrt{m_1 - 1} \exp\left(-\frac{q_p}{2} - 1,4\right),$$

where q_n – signal-to-noise ratio at the transceiver output, or inversely proportional to the signal-to-noise power ratio (6):

$$\frac{1}{q_p} \leq \frac{1}{2 \ln \frac{1}{\sqrt{m_1 - 1}} - 2,8} = \frac{1}{q_n} = \frac{const}{\sum_{j=1}^{n1} X_j(Y_j)}.$$

$P_{permissible\ noise\ level}$

The single-function (single-channel) systems with the indicators (1) (2) should have the greatest noise immunity or the greatest accuracy. Such indicators can serve as a target function of many parameters optimization problems. For them, the objective function may be inverse to q :

$$\min q^{-1}(\bar{X}) = k_1 / \prod_{j=1}^{n1} X_j.$$

At the same time, the cost constraint of the problem has a solution (7) and inversely proportional result (8):

$$X_{i(p)} = \frac{C_{E1}(\bar{X}_{(p-1)})}{n1 C'_i(X_{i(p-1)})}, \quad (7)$$

where p – iteration number optimum is:

$$F(X_{opm}) = q^{-1}(\bar{X}_{opm}) = \frac{k_1 \prod_{j=1}^{n1} C_j^1(X_{j(p)})}{[C_{E1}(\bar{X}_{(p)}) / n1]^{n1}}. \quad (8)$$

If the constraints are non-linear, then the first values of the vector of parameters and values of functional elements (PE), which are the initial plan, are substituted into the formula to obtain the vector of the solution of the first iteration.

The process of iterations continues until optimal solutions are obtained for the indicator, parameters and cost of PE. In this case, unlike the Wolf's method, the following happens:

1) using the separability of functions – solving a simple problem of any size in an analytical form immediately gives an idea of the nature of the optimum;

2) using a simple solution obtained in an analytical form (as a formula) as an iterative solution – solves the problem of multidimensionality;

3) if the communication function is linear, then this is the final solution;

4) if the communication function is not linear, then it can be estimated by the proximity criterion of approximation (up to 10% of the initial function) for all parameters:

$$\Delta X_i \leq \frac{0,2 C'_i(X_i)}{C''_i(X_i)},$$

where $C''_i(X_i)$ – second cost derivative;

5) for parameters that are in the region of satisfying approximation, it is necessary to limit the iteration step to the limit of this region.

The rule for stopping an iteration step can be the decision accuracy criterion:

$$X_{j(p)} \leq X_{ij(p-1)} \leq \sigma X_{j(p-1)},$$

where j – parameter number; p – is the number of the iteration step; $\sigma = 0,1$, т.е. 0,1=10% – relative accuracy of the solution.

This solution has the following advantages over the known methods of mathematical programming:

1) solving the problem of multidimensionality and possible consideration of all parameters;

2) the simplicity of solving the problem according to the conditional extremum, especially with a single communication function – there is no need to solve a system of nonlinear equations;

3) universality in relation to the form of the objective function and any communication functions, and with a complete set of unattached simpler tasks – universality for different classes of objective functions;

4) the nature of the convexity (convexity) and the effect only on the presence of extremum, which is required;

5) using the value in numbers only in the iteration procedure;

6) the solution (result) is obtained in the form of an algorithm and optimum in an analytical form, the ability to analyze in the region of satisfactory approximation, which is important for stochastic programming for determining confidence intervals;

7) technical parameters are sought in the form of inverse functions of "phase" parameters;

8) the result of optimization obtained in analytical form is worthy for efficiency analysis, including as an "exchange curve" according to Gutkin L.S. [5];

9) a valid solution of the problem in parts, and then stitching them together;

10) "exchange curves" make it possible to objectively estimate the optimum structure of LIMS (information and measurement channels), as well as signals, if LIMS are optimized for the same indicators [1].

Thus, in this example of optimization, the main idea of the new method of mathematical programming is laid, which eliminates the aforementioned previous shortcomings of the existing methods, which are indicated in the requirements for the method. This idea uses a linear approximation of a complex separable link function and the uniformity of the objective function.

In this case, the separability of the coupling function is not necessary, because the linearization of any constraint function leads to a linear, and hence, to a separable approximation. And the separability of the objective function is ensured by the monotonic transformation of variables.

The next significant advantage of separable programming is that it is possible in parts, as in block programming, to distribute the tasks of programming and then stitch their results together.

We consider the optimization task of the LIMS part, designed to combat noise (to increase the signal-to-noise power ratio), to expand to take into account the effect of measurement errors on the resulting error measurement:

$$F = \min \left[k_1 / \prod_{j=1}^{n1} X_j + \sum_{i=1}^{n2} X_i^2 \right], \quad (9)$$

at $C(\bar{X}) \leq C_d$, (10)

where $k_1 = const$; X_j – monotonic functions of technical and parasitic parameters of the influence of detunings, disturbances and non-ideals (the more they are, the better); X_i – errors due to the instability of the standards (the smaller they are, the better for the system).

The provision (cost) for the parameters of the first component in (9) is separate from the allocations for the parameters of the second component.

Therefore, there are two standard tasks: type (4) (5); by type (9), (10) – the minimum of the second component with restrictions on its allocations C_{d2} :

$$\min \sum_{i=1}^{n2} X_i^2, \quad (11)$$

at $C_{(i)}(\bar{X}_{(i)}) \leq C_{d2}$,

or

$$\sum_{i=1}^{n2} C_i^1(X_{0i})X_i \leq C_{E2}, \quad (12)$$

$$C_{E2} = C_{d2} - \sum_{i=1}^{n2} [C_i(X_{0i}) - C_i^1(X_{0i})X_{0i}].$$

The Lagrange function for problem (11), (12) has the following form:

$$L_2 = \sum_{i=1}^{n2} X_i^2 + \lambda_2 [C_{E2} - \sum_{i=1}^{n2} C_i^1 X_i].$$

From the condition:

$$\frac{\partial L_2}{\partial X_k} = 2X_k - \lambda_2 C_k^1 = 0,$$

we get the value:

$$X_k = \lambda_2 C_k^1 / 2,$$

which we substitute in condition (12) to get the value λ_2 .

Then the second problem has an analytical solution and an optimum, respectively:

$$X_{i(r)} = C_{E2}(\bar{X}_{(r-1)}) C_i^1(\bar{X}_{(r-1)}) / \sum_{i=1}^{n2} [C_i^1(X_i)]^2, \quad (13)$$

$$F_2(C_{E2}) = C_{E2} / \sum_{i=1}^{n2} [C_i^1(X_i)]^2. \quad (14)$$

Bridging the obtained solutions of two problems (7), (8) and (13), (14) is possible by solving a sequential simpler two-dimensional problem:

$$\sigma_\lambda^2 = F_1(C_{E1}) + F_2(C_{E2}), \quad (15)$$

$$C_{E1} + C_{E2} \leq C_E$$

The solution can be obtained by the Newton-Raphson method as an iterative formula.

For example, it is possible to find the optimum of the problem (9 – 11), at the already known optima of two particular problems:

$$F = \frac{A}{C_{E1}^{n1}} + \frac{C_{E2}^2}{B}, \quad (16)$$

at $C_{E1} + C_{E2} = C_E$, (17)

where $A = n1^{n1} \sum_{j=1}^{n1} C_j'$; $B = \sum_{i=1}^{n2} (C_i')^2$.

The task is decoupled by one variable, for example, by the substitution method. The solution is based on the following conditions:

$$\frac{dF}{dC_{E1}} = 0,$$

in analytical form by Newton-Raphson method from the equation:

$$C_{E1} = C_E - \frac{D}{C_{E1}^{n1+1}},$$

where

$$D = \frac{n1 AB}{2}.$$

Functions of the same type are achieved by replacing task variables with “phase” parameters.

The proposed new separable programming method also works well for the objective function, both as a product of functions of the same type, and as an addition with the corresponding monotonic variables.:

$$\min q = \min \prod_{i=1}^n X_i(Y_i) = \min [\exp \sum_{i=1}^n \lg X_i(Y_i)].$$

For example, assign:

$$Z_i(X_i) = \lg X_i(Y_i),$$

or

$$C_i(X_s) = C_i(\exp Z_i).$$

Also, on the contrary, additions of functions to entire functions can be represented as a product of variable functions.

Thus, if there are different parts of the problem, then it is possible to easily stitch the optimization results. Moreover, the simplification of the objective function leads to a monotonous complication of cost constraints, which are taken into account when calculating the derivatives of complex functions.

The mentioned features of the separable programming method and obtaining these advantages, it

is easy to adapt to almost any optimization problem for single-function and multifunctional LIMS or their information and measurement channels [1 – 4].

Conclusions

The proposed new separable programming method solves such problems as: multidimensionality, convergence of results, simplicity of constructing exchange curves, etc. It has the following advantages:

1. The problem of multidimensionality affects only in the first order (there is no need to solve a system of equations of the same type, because an analytical iterative solution is obtained by substitution into a constraint).

2. The universality of the optimization algorithm for arbitrary separable functions.

3. Fast finding of the iterative process, as in the second order gradient method with the regulation of the iteration step.

4. The solution is obtained in a general (analytical) form, which makes it possible to immediately obtain “exchange curves” and simplify the procedure for system analysis of optimization results [5].

5. The analytical view of the solution and the optimum allows you to immediately see and predict which production and qualities of LIMS and their FE should be developed further.

6. Convenience of the method for solving multiparameter problems with separable functions of the goal, where communication functions are allocations for the system, since these allocations are always global constraints.

7. Getting solutions to complex comparable block programming problems is simpler [1 – 4], because they are stitched together from solutions and optima of simpler standard problems.

8. When obtaining the optimum, which is difficult for analytical system analysis, its numerous efficiency analysis is simpler and all the other advantages of the method are retained.

9. The resulting solution algorithms are easy to program on personal electronic computers.

10. The use of the method is also possible for nonseparable objective functions if they are decomposed into polynomial series of low orders.

But at the same time, the effectiveness of the method decreases to the effectiveness of the Wolf's method [6].

11. Unlike conventional design methods of LIMS or other systems, where FE parameters are intuitively assigned, it is proposed to use all possible marketing statistics, which significantly optimizes the system.

12. Restrictions can be non-separable because they are still linearized.

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Метод сепарабельного програмування для вирішення багатомірних задач оптимізації параметрів лазерних інформаційно-вимірювальних систем

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Основним із складових теорії побудови (створення) лазерних інформаційно-вимірювальних систем (ЛІВС) є результат вирішення проблеми оптимізації системи і її функціональних елементів на множині структур, сигналів і технічних параметрів за вектором показників якості, які представлені в тактико-технічних вимогах з використанням витратних показників. Отримання результату вирішення проблеми оптимізації ЛІВС можливо за рахунок рішення комплексу проблем: системного аналізу та знаходження зв'язків вектору показників якості системи з вектором технічних параметрів; визначення проблем: нечіткості, зміни витратних показників; врахування проблеми багатомірності задач як вимоги до адекватності математичної і фізичної моделі ЛІВС тощо. Проте, в чисельному ряду алгоритмів, є важлива ланка, яка значною мірою визначає їх реалізацію і якість. Це – вибір найкращого методу, що вирішить перераховані задачі (проблеми), які зазвичай формуються у вигляді математичного програмування. Більшість постановочних задач оптимізації ЛІВС містять цільову функцію головним показником системи і функцію зв'язку, яка зазвичай буває вартістю або витратним показником. За умови наявності нечіткого показника вартості, доцільно лінеаризувати лише функцію зв'язку. Тоді, для спрощеного вирішення (у аналітичному виді) задачі, досить мати сепарабельну цільову функцію, яку можна перетворити на сепарабельну однотипну функцію. У статті обґрунтовано використання сепарабельного програмування в основі методу оптимізації ЛІВС. Такий метод дає значні переваги перед існуючими математичними методами та дозволяє зшивати результати задач оптимізації системи (структури, сигналів і технічних параметрів), що отримані від різних частин завдань. При цьому, спрощення цільової функції призводить до монотонного ускладнення обмежень за вартістю, які враховуються при розрахунку похідних від складних функцій. Метод, що пропонується, вирішує такі проблеми: багатомірності, збіжності результатів, простоти, побудови кривих обміну тощо. Метод можна застосовувати для вирішення задач оптимізації як одно функціональних, так і багато функціональних ЛІВС (інформаційних і вимірювальних каналів, а також функціональних елементів).

Ключові слова: оптимізація параметрів, вартість, лазерна інформаційно-вимірювальна система, функціональний елемент, сепарабельне програмування, багатовимірна задача.

Метод сепарабельного программирования для решения многомерных задач оптимизации параметров лазерных информационно-измерительных систем

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Основным из составляющих теории построения (создания) лазерных информационно-измерительных систем (ЛИИС) является результат решения проблемы оптимизации системы и ее функциональных элементов на множестве структур, сигналов и технических параметров по вектору показателей качества, которые представлены в тактико-технических требованиях с использованием затратных показателей. Получение результата решения проблемы оптимизации ЛИИС возможно за счет решения комплекса проблем: системного анализа и нахождения связей вектора показателей качества системы с вектором технических параметров; определения проблем: нечеткости, изменения затратных показателей; учета проблемы многомерности задач, как требования к адекватности математической и физической модели ЛИИС и т.д. Однако, в многочисленном ряде алгоритмов, есть важное звено, которое в значительной степени определяет их реализацию и качество. Это выбор наилучшего метода, решающего перечисленные задачи (проблемы), которые обычно формулируются в виде математического программирования. Большинство постановочных задач оптимизации ЛИИС содержат целевую функцию по главному показателю системы и функцию связи, которая обычно бывает стоимостью или расходным показателем. При условии наличия нечеткого показателя стоимости, целесообразно линейаризовать лишь функцию связи. Тогда, для упрощенного решения (в аналитическом виде) задачи, достаточно иметь сепарабельную целевую функцию, которую можно превратить в сепарабельную однотипную функцию. В статье обосновано использование сепарабельного программирования в основе метода оптимизации ЛИИС. Такой метод дает значительные преимущества перед существующими математическими методами и позволяет сшивать результаты задач оптимизации системы (структуры, сигналов и технических параметров), полученные от разных частей задач. При этом упрощение целевой функции приводит к монотонному осложнению ограничений по стоимости, которые учитываются при расчете производных от сложных функций. Предлагаемый метод решает проблемы многомерности, сходимости результатов, простоты, построения кривых обмена и т.д. Метод можно применять для решения задач оптимизации как однофункциональных, так и многофункциональных ЛИИС (информационных и измерительных каналов, а также функциональных элементов).

Ключевые слова: оптимизация параметров, стоимость, лазерная информационно-измерительная система, функциональный элемент, сепарабельное программирование, многомерная задача.