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THE METHOD OF PARAMETERS OPTIMIZATION OF THE MULTIFUNCTIONAL LASER INFORMATION-MEASURING SYSTEM ON THE MULTIPLICITY OF SIGNALS, STRUCTURES AND TECHNICAL PARAMETERS

The article poses and solves the problem of optimizing the parameters of a multifunctional laser information and measuring system for a polygon test complex on a multiplicity of signals, structures and technical parameters based on the minimum cost of the system, while limiting the accuracy of the measuring and noise protecting of the information channel. This task is an integral part of the construction of this system based on the basic tactical and technical requirements for the given structure and signals.

Hardware alignment for all measuring and information channels of the system assumes the use of its common part (transmit-receive), and signal combination – time, frequency, polarization, phase, structural and combined signal separation, respectively, through channels.

The developed method uses the existing methods of modern mathematical programming in the separable representation of value and represents the optimum in analytical form, due to which it allows to "sew" individual blocks of tasks into a common (single) solution. Analytical expressions for calculations are presented.

Keywords: *multifunctional laser information and measuring system, parameter optimization, measurement of motion parameters, flying vehicle*

Introduction

Formulation of the problem. In each single-function system there are expensive elements as the transmitting device, the antenna (transmitting optics) and the receiving device (receiving optics). The cost of all these elements of single-functional systems significantly exceeds the cost of the same elements of one combined (multifunctional) system. Losses due to the combination of signals in the channels where the corresponding functions are performed in a combined system can be completely compensated for by a gain in the cost spent on improving the system.

This intuitive prerequisite can be verified if all systems are optimized for tactical and technical requirements (TTR) on a set of parameters and will allow to compare the quality indicators at the total set cost (if you do the whole procedure of building a multifunctional system).

In this case, the formulation of the optimization problem must be universal and practically independent of the numerous operating conditions: range, wave band, measurement principle, the type of propagation of electromagnetic waves in the medium, and other nuances.

As a rule, separate functions of systems are realized in their individual channels. In this case, hardware alignment involves the use of some common part of the system for all channels, and signal alignment – temporary, frequency, polarization, phase, structural and combined separation of signals through channels. This circumstance brings functional, instrumental or economic advantages because otherwise it is required to create a large number of single-function systems in terms of the number of required functions.

Multifunctional (combined) information-measuring systems (MIMS) with a large number of channels are found mainly among radio engineering systems. However, the time has come for the development of laser (combined) MIIS (MLEI). This circumstance is due to the fact that despite their shortcomings, such as the influence of the atmosphere and the problem of finding a connection, they also have undeniable advantages – a wide bandwidth, high frequency stability, a large concentration of energy in a solid angle with a small antenna aperture (optics), good external and internal electromagnetic compatibility (EMC), concealment, insignificant dimensions and weight of receiving and transmitting devices, etc.

Deficiencies in the search for MLIMS are usually eliminated by integration with the radio engineering system or the use of beacons, and attenuation in the atmosphere can be eliminated not only by the method of getting into the "transparency windows of the atmosphere", but also by the method of burning the atmosphere, which requires high laser radiation powers and is still ineffective.

Thus, the optimization of the parameters of a multifunctional laser information and measuring system on a multitude of signals, structures and technical parameters is an important scientific task that requires a modern approach to its solution.

Analysis of literature. The construction of MLIMS on a set of technical parameters with a complex mutual search for communication with the beacon of the forward and reverse channels is described in [1–21]. For such MLIMS with several channels, the optimization (construction) task is significantly complicated because of the multifunctionality and, as a consequence, the multi-channel.

Combining the functions of MLIMS and its channels is a significant progress in its development, thanks to the works [1–3]. A significant role was played by the possibility and technique of selection of longitudinal modes of laser radiation [22–27], which opened up new possibilities for new high-precision principles and methods for measuring the parameters of the motion of aircrafts, even for measurements of angular (tangential) velocities, recognition and transmission of information.

Purpose of the article. Development of a method for optimizing the parameters of a multifunctional laser information and measuring system on a set of signals, structures and technical parameters.

Basic material

The use of selection of longitudinal modes of laser radiation makes it possible to obtain a wide variety of signals in the optical range in the form of a set of pairs of modes with the conversion (detection) to the frequencies of the radio engineering range in the form of stable frequencies of intermode beats for various applications: measurements of the parameters of the motion of flying vehicles, transmission of information, detection and recognition of signals [22–27].

Selecting signals at intermode beats significantly extends the capabilities of MLIMS, in addition, eliminates dark, noise photons and only stores signal photons, filters them in a narrow enough band at the radio frequency of intermode beats, i.e. significantly increases the noise immunity of the system by the number of times the number of times the band of the radio signal is already in the video signal band at the output of a conventional photodetector.

Existing laser systems (LS) are also multiparameter systems, since the same system performs at least signal search and mutual tracking in the direction of aircraft, as well as the reception and transmission of information.

Therefore, along with the restrictions imposed on the signal-to-noise ratio (q) at the output of the LS terminal, there are restrictions on the time of connection (t_n) with flying vehicle and tracking accuracy. The existence of these limitations is taken into account in [1–3], but in them the mutual influence of several measuring channels has not been reflected.

A description of the impact part of the equipment and its quality when entering MLIMS in touch with flying vehicle can be omitted in cases where existing systems this function runs radio systems. The same may be taken into account and new digital methods of measured parameters of movements (MPM) of flying vehicle, based on the properties of multimode laser radiation spectrum and longitudinal selector mod.

For MLIMS, the most objective criterion of optimality can be regarded as a conditional test, which takes into account the totality of the quality indicators presented in the TTR.

Modern multifunctional laser systems have many of TTR, which ensures successful operation and system generated. The main quality indicators MLIMS that takes into account when designing, first of all, it is worth:

– the accuracy of the MPM of flying vehicle;
– the MPM range of flying vehicle;
– interference-free transmission of information forward and reverse channels;
– precision matching binding and time scales;
– time measurement and communication of information;
– reliability of the functioning;
– electromagnetic compatibility;
– information transfer speed;
– system throughput;
– survivability;
– noise protecting;
– economy;
– weight and dimensions equipment specifications and its parts;
– ergonomics;
– other quality indicators.

When optimizing MLIMS for the schematic design phase, as well as for the evaluation of quality indicators marked easier to express them in a specific numerical form as a vector, which is self-descriptive of the quality of the main task. Vector of the above quality indicators can be used to optimize any systems. Quality indicators are interdependent and mutually conditioned. A more complete accounting results adopted by the MLIMS model more into line with the real system. And the task of optimization on indicators (criteria 1–15) equivalent optimal solution on a multitude of parameters at fixed signal structure and by the values of 13 independent criteria.

When choosing a MLIMS structure, which is optimized for MPM you can benefit from the flying vehicle engineering synthesis systems, such as heuristic (intuitive), but recent decisions contain in themselves the experience of the past, that does not always achieve the best value and is not the optimal solution to a multitude of structures. In this task, enlarged structure of the system believe the famous [24–27] with the most simple discriminant flow in channels that monitor measurable parameters of movement of aircraft.

The generalized structure of MLIMS does not differ significantly from typical systems. It accommodates an additional block of selector of longitudinal modes and a block of their selection – radio filters.

To formalize the objective function, it is necessary to specify the expression for determining the signal-to-noise ratio provided by the system in each channel (measuring and information), as well as the corresponding quality indicators.

We believe that the emission of a laser-transmitter MLIMS operating in a single-mode, power-stabilized mode, has a Poisson distribution of signal photons. We also assume that the probability of detection is determined only by the intrinsic, quantum noise, additive with the signal. What is a typical assumption when using LS with a small angle of view, with narrowband filters and receiver cooling. In this case, the probability of detecting a signal is defined as:

$$p_i = \sum_{n=n_0}^{\infty} \frac{S_i^n e^{-S_i}}{n!}, \qquad (1)$$

where n_0 – is the threshold of the system, the value of which can be estimated from the given probability of a false alarm; n – the parameter of the distribution of the number of signal photons; S_i – the average number of photoelectrons emitted by the photocathode due to irradiation with a useful signal either by a beacon or a transmitting device.

If the maximum radiation power optical source is equal to W_i, the energy of a useful signal at the input of the receiver with a view of weakening on the track distribution can be written as:

$$W_i \tau_i e^{-\gamma R} \frac{d^2}{\Theta_i^2 R^2} \prod_i T_i, \qquad (2)$$

where γ – is the complete attenuation of the signal on the track; R – the maximum distance between the transmitting and receiving systems, restricted to a necessary signal-to-noise ratio; d – the receiving antenna diameter; Θ – the width of the receiver diagram, respectively, of coarse or accurate tracking; $\prod_i T_i$ – the overall transmission ratio combined transmitter and receiver optics.

Then the average number of photoelectrons at the output of the photodetector or photodetector (FTD) will be written in the form:

$$S_i = \frac{W_i \tau_i e^{-\gamma R} d^2 \prod_i T_i \prod_i T_{i\ \text{T(гр)}} \eta_i}{\Theta_i^2 R^2 \hbar \nu_i}, \qquad (3)$$

where $\prod_i T_{i\text{T(гр)}}$ – is the overall transmission coefficient of the receiver's optics of coarse or precise targeting; $\hbar$ – the Planck's constant; ν_i – the frequency of the radiation of the laser transmitter; η_i – the quantum output of the photodetector (FTD).

If information is transmitted on the channel, provided the nature of the noise is of a quantum nature, the signal-to-noise ratio at the output of the direct detection system containing the receiver with an internal current coefficient according to [3] will be determined as:

$$q = \frac{\mu^2 W_{\text{прм}}}{4eF\text{п}_\text{и}}, \qquad (4)$$

where μ – is the modulation factor of light;

$$W_{\text{прм}} = S\hbar\nu\text{п}, \qquad (5)$$

where $W_{\text{прм}}$ – is the value of the signal power at the output of the photodetector (FTD); e – the electron charge; F – the noise factor, taking into account the increase in noise in the process of internal amplification; $\text{п}_\text{и}$ – information reception channel band.

Substituting (5) into (4) and using relation (3) for the average number of photoelectrons when receiving transmitter radiation, we obtain:

$$q = \frac{\mu^2 \eta_{\text{ТИ}} e^{-\gamma R_m} \left(W_\varepsilon \prod_i T_i \prod_i T_{\text{Т}i} \eta_\text{и} \text{Д}^2 \right)}{4\hbar\nu \Pi_{\text{ТИ}} \left(\Theta R_m \right)^2}, \qquad (6)$$

where $\eta_{\text{ТИ}}$ and $\eta_\text{и}$ – quantum yields of photodetectors (FTDs), respectively, accurate and coarse guidance.

The probability density of the detection of a signal represented in the form of a sum of the density of the Poisson distribution has a rather complex form, which makes it inconvenient for the subsequent solution of the problem of finding the optimal characteristics of the system.

At the same time, $S = 10$ the distribution of the Poisson law will have a form close to the triangular distribution [3].

Using the stochastic approximation method, the probability of detecting a signal with an error ≤ 25 % can be approximated by a broken line (7) [3].

With the number of signal photoelectrons ≥ 100, which is typical for the information transfer mode with high speed, this error will be insignificant.

If we limit this approximation to simplify the probability of detecting a signal, it can be represented as:

$$p_i = 1 - \frac{\hbar^2}{\sqrt{2\pi} S_i^{3/2}} . \qquad (7)$$

For the formulation and statement of the optimization problem for MLIMS parameters, let's take the example of the channel for measuring the angular (tangential) velocities of a flying vehicle with the open principle of action (work).

Let us consider such an indicator of the quality of a given system as a random measurement error because the systematic error is taken into account in time so that it does not exceed the random error.

The error in measuring the angular, and in fact the tangential velocity of a flying vehicle, or other parameter, is one of the indicators of the quality of the system that determines its accuracy.

The variance of the random error and the corresponding measurement accuracy in the channel of the angular (tangential) speeds of the flying vehicle is determined by the first and final fronts of each half-wave motion of the intermode modulation of the partial radiation pattern (RP) of the laser radiation (LR) and the signal-to-noise ratio:

$$\sigma_x^2 = \frac{\sigma_ш^2}{(U_x^1)^2} , \qquad (8)$$

where $\sigma_x^2, \sigma_ш^2$ – is the respectively, the variance of the measurement error and the noise dispersion at the output of the photodetector (FTD); $(U_x^1)^2$ – the first derivative of the envelope voltage on the fronts of the angular auto-tracking signal flying vehicle in the direction.

Given the steepness of the envelope signals of intermode beats, which repeat the shape of RP LR, the error in measuring the angular velocity of a flying vehicle is determined by formula (8).

In general, the dispersion variance of the MPM flying vehicle can be represented in the form of additions:

1) the factorized complex function of the technical parameters, which reflects the effect on the energy potential of the fluctuation noise;

2) the functions of complements of variances in the errors of standards;

3) the functions of the effect of the atmosphere on the dispersion of measurements;

$$\min D\left[\frac{\Delta V_r}{V_r}\right] = \min_{\left\{\begin{matrix} X_i \\ X_j \end{matrix}\right\}} \left\{ \frac{\text{const}}{\prod_{j=1}^{n_1} X_j(Y_j)} + \sum_{i=1}^{n_2} X_i^2(Y_i) \right\} + D_c , \qquad (9)$$

where $X_j(Y_j)$ – is the technical parameter, or a monotonic function from it, such that the larger it is, the better, from the technical parameter (factor parameter) that affects the energy loss of the signal; $X_i(Y_i)$ – monotonous function of instability of standards, such that the smaller it is, the higher the accuracy of the MPM of the flying vehicle; D_c – loss of accuracy of the MPM of the flying vehicle due to the heterogeneity of the atmosphere.

In this case, the restriction on the parameter or function is written as:

$$X_{j\max} \ge X_j \ge 0 , \quad X_i \ge X_{i\min} . \qquad (10)$$

If the dependence of MLIMS value on technical parameters is known in the form [27]:

$$C = C(\overline{X}(\overline{Y})) , \qquad (11)$$

then this is already a problem of non-linear stochastic programming, which has already been solved in part for two indicators with two or three parameters and for radio systems [3].

In general, to optimize the technical parameters of MLIMS, there are three main stages for each channel (measuring and information):

1) analysis of parasitic and other phenomena, effects and determination of dependencies $X_{j,i}(Y_{ji})$ of the type (9);

2) system analysis, i.e. obtaining dependencies of quality indicators on the parameters of a system of the type (9; 11);

3) solving the problem of optimizing the system parameters on a set of technical and other parameters.

Conclusions

Thus, the solution of the overall optimization problem for MLIMS parameters is related to:

1) the definition of the system, infrastructure and structure at the level of functional elements, which are created in the form of constructively ready, if possible, standard modules;

2) optimization of the system parameters for precision, economic and other indicators, which also take into account a number of additional requirements: EMC conditions and noise immunity, better isolation of the transmitting and receiving paths, etc;

3) obtaining "exchange curves" [27];

4) pairwise equalization of quality indicators of different in structure, the principles of the operation of the channels (measuring and information channels), but according to TTR;

5) selection of optimal channels on three sets (signals, structures and technical parameters).

Previously, the cost of the channel (corresponding) part of the LAN was minimized while maintaining the specified signal-to-noise ratio as a function of quality by the Lagrange multiplier method in the usual numerical form. However, to solve such problems, the article proposes a new method of mathematical (separable) programming, which allows to obtain a solution and result in an analytical form, suitable for a whole class of cases. The solution is obtained in the form of a simple iterative formula, which has a universal character, which makes it possible to reduce the amount of computation.

The article formalizes and solves the problem of optimization of MLIMS parameters in the form of the problem of degenerate dynamic programming based on the minimum cost criterion, while limiting the quality of measuring and information channels.

The signal-to-noise ratio at the MLIMS output, as a quality measure, depends on the variance of the error of the MPM of the flying vehicle, the dispersion of the noise at the output of the photodetector (FTD), and the envelope voltage at the edges of the LA auto tracking signal. The main stages of optimization of technical parameters of MLIMS are determined.

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МЕТОД ОПТИМІЗАЦІЇ ПАРАМЕТРІВ БАГАТОФУНКЦІОНАЛЬНОЇ ЛАЗЕРНОЇ ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНОЇ СИСТЕМИ НА МНОЖИНІ СИГНАЛІВ, СТРУКТУР І ТЕХНІЧНИХ ПАРАМЕТРІВ

Г.В. Альошин, О.В. Коломійцев, О.В. Кулєшов, К.К. Кулагін, А.М. Ткачов

У статті поставлена і вирішена задача оптимізації параметрів багатофункціональної лазерної інформаційно-вимірювальної системи для полігонного випробувального комплексу на множені сигналів, структур і технічних параметрів за критерієм мінімуму вартості системи при обмеженні на точність вимірювальних і стійкість інформаційного каналів. Це завдання є складовою частиною побудови даної системи за основними тактико-технічними вимогами при заданих сигналах і структурі.

Апаратурне поєднання для всіх вимірювальних і інформаційного каналів системи передбачає використання загальної її частини (приймально-передавальної), а сигнальне поєднання – часове, частотне, поляризаційне, фазове, структурне і комбіноване розділення сигналів відповідно по каналах.

Розроблений метод використовує існуючі методи сучасного математичного програмування у сепарабельному поданні вартості і представляє оптимум в аналітичному вигляді, завдяки чому дозволяє «зшивати» окремі блоки задач в загальне (єдине) рішення. Представлені аналітичні вирази для розрахунків.

Ключові слова: *багатофункціональна лазерна інформаційно-вимірювальна система, оптимізація параметрів, вимірювання параметрів руху, літальний апарат.*

МЕТОД ОПТИМИЗАЦИИ ПАРАМЕТРОВ МНОГОФУНКЦИОНАЛЬНОЙ ЛАЗЕРНОЙ ИНФОРМАЦИОННО-ИЗМЕРИТЕЛЬНОЙ СИСТЕМЫ НА МНОЖЕСТВЕ СИГНАЛОВ, СТРУКТУР И ТЕХНИЧЕСКИХ ПАРАМЕТРОВ

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В статье поставлена и решена задача оптимизации параметров многофункциональной лазерной информационно-измерительной системы для полигонного испытательного комплекса на множестве сигналов, структур и технических параметров по критерию минимума стоимости системы при ограничении на точность измерительных и помехоустойчивость информационного каналов. Эта задача является составной частью построения данной системы по основным тактико-техническим требованиям при заданных сигналах и структуре.

Аппаратурное совмещение для всех измерительных и информационного каналов системы предполагает использование общей ее части (приемо-передающей), а сигнальное совмещение – временное, частотное, поляризационное, фазовое, структурное и комбинированное разделение сигналов соответственно по каналам.

Разработанный метод использует существующие методы современного математического программирования при сепарабельном представлении стоимости и представляет оптимум в аналитическом виде, благодаря чему позволяет «сшивать» отдельные блоки задач в общее (единое) решение. Представлены аналитические выражения для расчетов.

Ключевые слова: *многофункциональная лазерная информационно-измерительная система, оптимизация параметров, измерение параметров движения, летательный аппарат.*