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SYMBOLICAL COMBINATORY MODEL FOR SOLVING THE PROBLEM OF EIGENVALUES IN TASKS OF IDENTIFICATION OF DYNAMIC OBJECTS

SIMBOLISKS KOMBINATORISKS MODELIS ĪPAŠVĒRTĪBU PROBLĒMAS ATRISINĀŠANAI DINAMISKO OBJEKTU IDENTIFIKĀCIJAS UZDEVUMOS

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1. Introduction

The calculation of matrix eigenvalues plays an important role in the modern methods of signal processing. Engineers who develop the structures of technical objects must know the base frequencies and optimal modes of these objects. In the algorithms of identification, ill-conditioned systems of equations are used and it leads to the reduced numerical stability of algorithms and increased sensitivity to noise. Therefore, to find accurate solutions, it is necessary to estimate the degree of numerical stability of the used algorithms. As its estimate, the condition number, in the form of the ratio of the maximal eigenvalue of the system's matrix to the minimal eigenvalue, is used:

$$Cond = \lambda_{\max} / \lambda_{\min} . \quad (1)$$

This parameter can be used also for choosing the most informative parts of the signals, on which the matrix should be formed. The conditionality of the equation system depends on the sampling rate of signals *T*. Because of that, the value of *T* can be chosen with the use of the condition number (1). Thus, the definition of the eigenvalues of identification matrix has a practical value. However, the range of their change is wide and it influences the accuracy of their calculation using the traditional numerical methods. It leads to the necessity of development of non-conventional methods for calculating the eigenvalues. The developed algorithm should possess the property of decomposition, allowing to represent it in the form of a parallel algorithm. In this case, the architecture of the algorithm will be coordinated with the parallel architecture of computers working in parallel modes of calculations. It allows to reduce the time necessary for solving the problem.

2. Finding eigenvalues of matrix of system of identification equations

The accuracy of calculating the eigenvalues depends on the degree of conditionality of the initial matrix. For Toeplitz matrices, which are used in test modes of identification [1]

$$Y \cdot \overline{\beta} = \overline{y} \tag{1}$$

the conditionality usually is low. Therefore, such problems need application of more exact algorithms for calculating the eigenvalues and condition numbers.
The eigenvalues of a matrix are defined as the roots of the characteristic polynomial

$$P(\lambda) = (-1)^n [\lambda^{\,n} - p_1 \lambda^{\,n-1} + p_2 \lambda^{\,n-2} - \cdots + (-1)^n p_n]. \tag{2}$$

It is determined from the expression of the determinant of matrix $(Y - \lambda E)$:

$$P(\lambda) = \varphi Dpv * (Y - \lambda E); \quad Y - \lambda E = \begin{bmatrix} a_{11} - \lambda & & \cdots & a_{1n} \\ a_{21} & a_{22} - \lambda & \cdots & a_{2n} \\ .. & .. & \cdots & .. \\ a_{n1} & a_{n2} & \cdots & a_{nn} - \lambda \end{bmatrix}. \tag{3}$$

The coefficients of the polynomial are found by opening the determinant and grouping its factors according to their degrees λ^m. Here, the operator φDet is introduced that transforms the matrix into its determinant. Errors arise at the calculation of coefficients of the characteristic polynomial of the matrix, and then they amplify at the calculation of its roots, which are the eigenvalues of the matrix. Therefore, it is necessary to develop algorithms for finding the characteristic polynomials that would have higher accuracy in comparison with the existing numerical methods. For such algorithms, there are many different modifications.
For example, in the Frobenius method, the operations of similarity transformations of the initial matrix *Y* with the help of auxiliary matrixes *M* are used. The matrix *C*, in the Frobenius form, is found as a product

$$C = M_1^{-1} \cdots M_{n-2}^{-1} M_{n-1}^{-1}\, Y\, M_{n-1} M_{n-2 \cdots} M_1. \tag{4}$$

The result of the similarity transformations turns out as the following matrix:

$$C = \begin{bmatrix} p_1 & p_2 & \cdots & p_{n-1} & p_n \\ 1 & 0 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 1 & 0 \end{bmatrix}. \tag{5}$$

The first line of *C* will consist of the coefficients of the characteristic polynomial. From the formula (4), it is visible, that on some step there can arise a degenerate situation. In this case, the auxiliary matrix *M* will be ill-conditioned and it will lead to errors. The algorithm fails and the process of calculations should be stopped. The problem is that there are no methods for forecasting the occurrence of degenerate situations. Therefore, it is expedient to use an algorithm that does not require the use of inverses of similarity matrices.
From the linear algebra, it is known, that the coefficients of a polynomial can be expressed as the sum of all possible angular minors of the matrix *Y*. Their values are found, starting with the first order, and ending with the *n*-th order:

$$p_1 = \sum_{i=1}^{n} A_{i\,i};\; p_2 = \sum_{i=1}^{n} \varphi Det * \begin{bmatrix} A_{i\,i} & A_{i\,j} \\ A_{j\,i} & A_{j\,j} \end{bmatrix};$$

$$p_3 = \sum_{i=1}^{n} \varphi Dvp * \begin{bmatrix} A_{i\,i} & A_{i\,j} & A_{i\,k} \\ A_{j\,i} & A_{j\,j} & A_{j\,k} \\ A_{k\,i} & A_{k\,j} & A_{k\,k} \end{bmatrix}; \cdots p_n = \varphi Dvp * A. \tag{6}$$

The complexity of the operation of determining the minor is determined by the character of the extracted sub-matrix.

3. SC model for Knonecker product

The elements of the initial matrix $[Y]_{rL} = \sum_{i=1}^{n} H_i \, q^{\,r+L}$; $q_i = \exp(-a_i T)$ are formed from the values of the dynamic process which are connected to their coordinates. The indices of rows *r* and columns *L* are used as the powers of the discrete poles. Using the operators *Arang* for their allocation over the discrete poles, we shall have

$$[Y]_{rL} \Rightarrow \varphi Sum * \left\{ \left[\overline{q}^{(n)} * Arang(r) \right] \otimes \left[\overline{q}^{(n)} * Arang(L) \right] \otimes \overline{C}^{(n)} \right\}; \tag{7}$$

$$\left[\overline{q}^{(n)} * Arang(r) \right]^{T} \Rightarrow \left[q_1^{\,r} \; q_2^{\,r} \cdots q_n^{\,r} \right]; \left[\overline{q}^{(n)} * Arang(L) \right]^{T} \Rightarrow \left[q_1^{\,L} \; q_2^{\,L} \cdots q_n^{\,L} \right] \tag{8}$$

Here the operator of summation φSum is introduced. For finding the minors, the operator $\varphi Dpv(\arg)$, which properties have been investigated in [5, 7, 8], is used. As its argument, the vectors $\overline{r}$ and $\overline{L}$, describing the coordinates of the sub-matrix for which the minor is calculated, are used. We use the designation of the argument as Kronecker lexicographic product

$$\arg = ims_1 \times ims_2 \, ; \, ims_1 = \overline{r} \, ; \, ims_1 = \overline{L} \, . \tag{9}$$

In general, the structure formed using the operator $\varphi Dpv(\arg)$ can be represented by a SC model in the form of a graph which branches will consist of partitions of a fixed number. In [5, 8, 10, 11], its properties have been investigated and it was shown, that its configuration has a parallel architecture. Its structure can be changed with the help of the indices that form the argument set of the operator of graph formation $\varphi Gr(\arg)$. We shall consider the application of such approach for solving the considered problem. For this purpose, it is necessary to consider the character of the symbolical expressions obtained in the branches of the graph. They are defined by the structure of the expressions placed in the cells of the initial matrix, the order of the allocated sub-matrices, and their coordinate components. As shown in [6, 8, 10], the symbolical expressions can be generated on the basis of the formalized ordered numerical sequences $G(k,n)$. Here the indexes are connected to order of the minor and the parameters of sub-matrices $[Y]_{rL}$ [1].

The symbolical expressions of products in the graph branches can be represented as positional Kronecker products of vectors generated from the intervals of the natural sequence

$$Dec_{i \in \overline{1.m}} (\overline{1.n_i}) \Rightarrow (\overline{1.n_1}) \times (\overline{1.n_2}) \times \cdots \times (\overline{1.n_n}) \, . \tag{10}$$

As shown in [5, 6], they lead to the decomposition consisting of the set of ordered numerical sequences $G(k,n)$:

$$Dec_{i \in \overline{1.m}} (\overline{1.n}\,)_i \Rightarrow \bigcup_{i \in \overline{1.m}} \varphi Perm * \{ G(m,n) * Arang[\varphi Perm * Part(i) * m] \} \, . \tag{11}$$

The minors can be formed with the use of the expressions (11) which are operated on by the operators $\varphi Dpv(\arg)$ which create the local structures in the graph. In the considered problem, the elements of the matrix *Y* represent sums containing an identical number of addends. Using the properties of the $\varphi Dpv(\arg)$ [1], we get

$$\varphi Dvp(\arg) * \left[Dec_{i \in \overline{1.m}} (\overline{1.n}\,) \right] \Rightarrow \varphi Dvp(\arg) * [\varphi Perm * G(m,n)] . \tag{12}$$

Into this expression we shall bring the parameters of the extracted sub-matrix

$$\varphi Dpv(\overline{r} \times \circ \, \overline{L}) * \widetilde{q} \Rightarrow \left[\widetilde{q} * Arang\left(\varphi Perm * \overline{r} \right) \right] \cdot \varphi \Pi r * \left[\widetilde{q} * Arang(\overline{L}) \right] . \tag{13}$$

Using the principle of the equivalent representation [10, 11], we shall find the expression for arbitrary components of the numerical sequence $\widetilde{q} \in G(m,n)$:

$$\varphi Dvp(ims_1 \times \circ\, ims_2) * \left[\varphi Perm * \widetilde{q}^{(n)}\right]; \quad ims_1 = \widetilde{r}\,; ims_2 = \widetilde{L} \,. \tag{14}$$

For this purpose, we shall introduce the operator of allocation of permutations of the indices over the elements of $\widetilde{q}$. Using their properties [1], we have

$$\begin{aligned} &\varphi Dvp(\widetilde{r} \times \circ \overline{L}) * \left[\varphi Perm * \widetilde{q}^{(n)}\right] \Rightarrow \\ &\quad \Rightarrow \left[\widetilde{q}^{(n)} * \varphi Arang(\varphi Perm * \widetilde{r})\right] \cdot \circ \left(\widetilde{q}^{(n)} * Arang(\overline{L})\right). \end{aligned} \tag{15}$$

In [4], it has been shown, that the first multiplier can be transformed into a vector which components will consist of the differences of the discrete poles. This operation can be represented by the operator

$$\varphi Fg * \widetilde{q}^{\,(n)} \Rightarrow FG(\widetilde{q}^{\,(n)}) \Rightarrow \coprod_{i,j \in \overline{1.N}} \left(q_{\,i} - q_{\,j}\right). \tag{16}$$

The operator $\varphi Arang(\varphi Perm * \widetilde{r})$ in (15) places the indexes of powers over the elements of the components of $\widetilde{q}$ taking into account the character of the permutations. According to the properties of the operator $\varphi Dpv(\arg)$ [1], considering the (16), we have

$$\begin{aligned} &\varphi Dvp(\widetilde{r} \times \circ \overline{L}) * \left[\varphi Perm * \widetilde{q}^{(n)}\right] \Rightarrow \\ &\quad \Rightarrow \left\{\varphi Sum * \left[\overline{\varphi Fg(\widetilde{r}) * \widetilde{q}^{(n)}}\right]\right\} \cdot \circ \left(\widetilde{q}^{(n)} * Arang(\overline{L})\right). \end{aligned} \tag{17}$$

In the expression (12), the operator $Arang\left[\varphi Perm * Part(i) * m\right]$ is used. Using the property of the convertibility of operators [1], we find

$$\varphi Perm * \left[\widetilde{q}^{(n)} * Arang(\overline{L})\right] \Rightarrow \widetilde{q}^{(n)} * Arang(\varphi Perm * \overline{L}) \,. \tag{18}$$

Using the obtained results, we shall receive the expression of the SC model for transformation of the product (11) in the symbolical form:

$$\begin{aligned} &\varphi Dpv * \overline{G(n,m)} \Rightarrow \varphi Sum_{\,i} \left\{\left[\widetilde{q}_i * \varphi Arang(\varphi Perm * \circ \overline{r})\right] \times \circ \right. \\ &\quad \left. \times \circ \left[\widetilde{q}_i * \varphi Arang(\varphi Perm * \circ \overline{L})\right]\right\}. \end{aligned} \tag{19}$$

Here the component $\widetilde{q}_{\,i}$ is found with the help of the operator of re-addressing

$$\varphi Adres\left[\overline{G(n,m,)}\right] * \widetilde{q}^{\,(n)} \Rightarrow \widetilde{q}_i \,. \tag{20}$$

that was used in [7]. It allows to map the index expressions into the expressions consisting of real parameters. Using such operator, the components are formed from the weight factors H_i contained in the dynamic process $\left[Y\right]_{r\,L} = \sum_{i=1}^{n} H_i \, q^{\;\;r+L}$ as

$$\varphi Adres(G(n,m)_i * \overline{H}^{(n)} \Rightarrow \varphi \Pi r * \left[\overline{H}^{(n)}\right]_i \,. \tag{21}$$

They will enter as multipliers in the expressions of the minors.

4. SC model for coefficients of characteristic polynomial

The argument sets of the operators forming the angular minors (6) are direct lexicographic products of vectors. They are formed from the components of numerical sequences

$$Arg(k) \Rightarrow \overline{[G(k,n)]} \otimes \circ \overline{[(G(k,n)]}. \quad (22)$$

It leads to the product of vectors formed from the results of applying the operators $\varphi Dpv(\arg)$:

$$\overline{u} \otimes \overline{u} \Rightarrow \left[\varphi Dvp[G(k,n)] * Q_i^{[k\times n]}\right] \otimes \left[\varphi Dvp[G(k,n)] * Q_i^{[k\times n]}\right]. \quad (23)$$

If the coefficients of *H* are not equal to one, the (23) will have the multiplier $\overline{\mu}_k$ generated from these coefficients:

$$\varphi \Pi r * \left[\varphi Adres(G(k,n) * \overline{C}^{(n)}\right] \Rightarrow \left[\overline{\mu}_k = f(\overline{C})\right]. \quad (24)$$

The components of the vectors (23) are formed with the help of the operators (16) from which the following sums are formed:

$$[\alpha(s)]_{ki} \Rightarrow \varphi Sum * \left\{\varphi Fg * \left[\left(\varphi Adres * (G(s,n) * \widetilde{q}^{(n)}\right)_{ki}\right]\right\}. \quad (25)$$

The coefficient of the characteristic polynomial p_K (6) is determined by summation on all components of ims_{ki}:

$$p_K \Rightarrow \varphi Sum_{i \in \overline{1.N}} * \left\{[\alpha(s)]_{ki}^{2}\right\}. \quad (26)$$

The expressions formed by the operator φFg depend on the structure of the component $ims(M)_i$. Generally it should be represented in the form of decomposition into the regular segments

$$ims(M)_i \Rightarrow \left[\left(m_i * Arang(p)\right) \oplus \left(r \in \overline{0.k}\right)\right] \otimes \left[\left(m_i * Arang(p)\right) \oplus \left(r \in \overline{0.k}\right)\right]. \quad (27)$$

They are operated on by the operator φFg. Such decompositions arise in the results obtained using the operators $\varphi Dpv(\arg)$:

$$\varphi Dpv\{ims(M)_i\} * \widetilde{q}_n \Rightarrow \left[\left(\varphi \Pi r * \widetilde{q}_n\right)^{Z}\right] \cdot \left[\left(\varphi FG * \widetilde{q}_n\right) * Arang(2)\right];\ z = 2m_i. \quad (28)$$

Thus, the part of the operations for formation of minors can be executed in the index space formed by the coordinate components. They should be transformed using the operators of partitioning into the unions of sets of regular segments

$$ims \Rightarrow \varphi Part(1.s) * \widetilde{r}^{(n)} \Rightarrow \bigcup_{i \in \overline{1\ S}} z_j \oplus (1.k_i). \quad (29)$$

To each of them, the operator (16) is applied:

$$\varphi Fg(ims) * \widetilde{q} \Rightarrow \varphi \Pi r_{j \in \overline{1.S}} * \left\{\varphi \Pi r * \left(\widetilde{q}_j * Arang(z_j)\right) \cdot FG(\widetilde{q}_j)\right\};. \quad (30)$$

As it is mentioned above, a formalized graph can be applied as the operator of decomposition. It is formed on the basis of the residual combination principle [5]. On the basis of operation (30), the initial graph can be transformed into the new form in which the vertices will contain elements of FG:

$$\widetilde{q} * \varphi Arang * \left\{Gr\left[\bigcup_{i \in \overline{1\ S}} z_j \oplus (1.k_i)\right]\right\} \Rightarrow Gr\left[\varphi Fg\left\{\bigcup_{i \in \overline{1\ S}} z_j \oplus (1.k_i)\right\} * \widetilde{q}\right]. \quad (31)$$

The multipliers $\varphi \Pi r * \left(\widetilde{q}_j * Arang(z_j)\right)$ can be allocated in the accompanying graph. In this case, the expression (31) is a direct product of two graph structures. The use of such representation allows to improve the parallel properties of the algorithm and to simplify the technology of programming.
Using the properties of the operators [1], we get

$$\varphi Dpv * \overline{G(n,m)} \Rightarrow \varphi Sum\ _i\{[\tilde{q}_i * \varphi Arang(\varphi Perm * \circ \bar{r})] \times \circ$$
$$\times \circ [\tilde{q}_i * \varphi Arang(\varphi Perm * \circ \bar{L})]\}; \quad \tilde{q}_i \in \overline{G(n,m,\bar{q}^{(n)})}. \tag{32}$$

Both factors can be transformed with the help of the operator (16) into more compact forms. In them, the structures of FG turn out as determinants of the matrices containing the power of the discrete poles. The partitioning of the coordinate component by the algorithm (29) is equivalent to partitioning such matrixes into the corresponding sub-matrices $W(ims_i)$. This result can be used for creating the algorithm

$$\varphi Dpv(ims_1 \times \circ ims_2) * B \Rightarrow [\varphi Dpv * W(ims_1)] \cdot [\varphi Dpv * M^{(k\times k)}] \cdot$$
$$\cdot [\varphi Dpv * W(ims_2)] \Rightarrow \alpha_1(FG) \cdot [\varphi Dpv * M^{(k\times k)}] \cdot \alpha_2(FG). \tag{33}$$

Taking into the account the (23) $\alpha_1(FG) = \alpha_2(FG)$ this expression can be represented as

$$\varphi Dpv(ims_k \times \circ ims_k) * Y \Rightarrow [\alpha_k(FG)]^2 [\varphi Dpv * M^{(k\times k)}]. \tag{34}$$

The matrix *M* is formed from the weight factors *H*. In general, the coordinate components can differ from each other. Therefore we have

$$\varphi Dpv(\bar{r} \times \circ \bar{L}) * Y \Rightarrow \tilde{C}_i \cdot \alpha_1(\bar{r}) \cdot \alpha_2(\bar{L}); \tag{35}$$
$$\alpha_1(\bar{r}) \Rightarrow \varphi Sum * [(\varphi FG(\overline{r_1}) * \tilde{q}_{i1}) \otimes (\varphi FG(\overline{r_2}) * \tilde{q}_{i2}) \otimes \psi(\overline{r_2})]; \tag{36}$$
$$\alpha_2(\bar{L}) \Rightarrow \varphi Sum * [(\varphi FG(\overline{L_1}) * \tilde{q}_{i1}) \otimes (\varphi FG(\overline{L_2}) * \tilde{q}_{i2})] \otimes \psi(\overline{L_2}). \tag{37}$$

Here the $\psi(\overline{r_2})$, $\psi(\overline{L_2})$ are formed as powers of z_j (31) of the components $\tilde{q}_i$. These expressions can be used for the formation of expressions of inverse matrices *Y*. In this case, the following product is formed:

$$\varphi Dpv * [\bar{q} * Arang(\varphi Perm * \bar{r})] \Rightarrow \varphi Sum * \{[\varphi FG * G(v_1, n)] \otimes$$
$$\otimes [\varphi FG * G(n - v_1, n)] \otimes \bar{g}_r\}; \quad G(v_1, n)_i \circ G(n - v_1, n)_i = n. \tag{38}$$

In it, the diagonal matrixes can be allocated. In that specific case, the $\bar{r}$ can be an interval of the natural series. In (34), it results in the allocation of the structures

$$\varphi Dpv * [\bar{q} * Arang(\varphi \Pr m * \bar{r})] \Rightarrow \varphi FG * \bar{q} \Rightarrow \coprod_{i,j \in 1N} (q_i - q_j). \tag{39}$$

From the obtained results, it is possible to draw the following conclusions. When finding the angular minors, the argument sets of the operators φDpv are direct products of vectors which are formed from the component of numerical sequences $G(k,n)$. It is proved by the fact, that the algorithm possesses a parallel structure. Really, each factor can be represented in the form of the decomposition

$$p_k \Rightarrow \varphi Sum * \left\{ \bigcup_{j=1}^{N(K)} \varphi Dpv * [\varphi Adres(G(k,n) \otimes \circ G(k,n)) * Y] \right\}. \tag{40}$$

The parallel properties also show in that the decompositions arise at the use of numerical sequences in the operators of addressing $\varphi Adres[G(k,n)] * \tilde{q}^{(n)}$. The used graph structures represent the sums of the expressions formed in its branches. They can be calculated independently and then summed. The architecture of the graph can be flexibly changed by changing the parameters of the argument sets of operators. Therefore, the parallel architecture can be easily coordinated with the parallel structure of the computer using software methods.

5. Conclusions

The traditional methods for finding the characteristic polynomials require operations of inversion of auxiliary matrices of similarity transformation. For this reason, when these matrixes become ill-conditioned, the algorithms for calculating the eigenvalues fail. The algorithm, developed on the basis of a symbolical combinatory model, has better numerical stability, allows to supervise the computing process and to correct its properties.

The algorithm possesses the recurrent property and it allows to develop methods for lowering its complexity and using economical methods of programming.

Theoretical conclusions can be made from the derived analytical expressions. The values of the coefficients of the characteristic polynomial depend on the distances between the discrete poles of the object's transfer function. They are included as factors into the formulas of its coefficients. With the reduction of sampling rate of signals T, these distances decrease and their values can have the same order of magnitude as the noise. With the reduction of T, the discrete poles approach non-informational values close to one. In such cases, reliable calculation of eigenvalues becomes impossible. Therefore, restrictions should be imposed on the value of T.

The algorithm, developed on the basis of symbolical combinatory models, possesses the property of decomposition. It allows applying it in computers working in the modes of parallel calculation. In this case, time necessary for solving the problem can be significant reduced.

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Burovs G. Simbolisks kombinatorisks modelis īpašvērtību problēmas atrisināšanai dinamisko objektu identifikācijas uzdevumos

Rakstā apskatīta īpašvērtību noteikšanas problēma dinamisko objektu identifikācijas vienādojumu sistēmas matricai. Tradicionālajām skaitliskajām metodēm piemīt virkne būtisku trūkumu. Uz simbolisko kombinatorisko modeļu pamata ir izstrādāts jauns precīzāks algoritms raksturvienādojuma koeficientu noteikšanai, kas ļauj precīzāk aprēķināt tā saknes– matricas īpašvērtības. Algoritmam piemīt dekompozīcijas īpašība, tādēļ to iespējams realizēt datoros, kas darbojas paralēlos skaitļošanas režīmos. Iegūtās analītiskās izteiksmes ļauj izdarīt virkni svarīgu teorētisku secinājumu. Algoritmam piemīt rekursīvas īpašības, kas ļauj izmantot metodes tā sarežģītības samazināšanai.

Burov G. Symbolical Combinatory Model for Solving the Problem of Eigenvalues in Tasks of Identification of Dynamic Objects

The problem of calculating the eigenvalues of the matrix of systems of identification equations is considered. Traditional numerical methods possess a number of significant drawbacks. On the basis of symbolical combinatory models, a new more precise algorithm for finding the coefficients of the characteristic polynomial is developed. Therefore, as matrix eigenvalues are its roots, they can be calculated more precisely. The algorithm possesses the property of decomposition and, consequently, it can be applied in computers working in the modes of parallel calculation. Derivation of analytical expressions allows applying new methods of regularization and making a number of important theoretical conclusions. The algorithm has recursive properties and it allows to apply methods for reducing its complexity.

Буров Г. Символьная комбинаторная модель для решения проблемы собственных значений в задачах идентификации динамических объектов

Рассмотрена проблема определения собственных значений матриц систем уравнений идентификации динамических объектов. Традиционные численные методы обладают рядом существенных недостатков. На основе символьных комбинаторных моделей разработан новый более точный алгоритм определения коэффициентов характеристического полинома. Поэтому его корни, являющиеся собственными значениями матрицы, могут быть вычислены более точно. Алгоритм обладает свойством декомпозиции и поэтому может быть применен в ЭВМ, работающих в режимах параллельных вычислений. Получение формульных выражений для коэффициентов позволяет применить новые методы регуляризации и сделать ряд важных теоретических выводов. Алгоритм обладает рекурсивными свойствами и это позволяет применить методы понижения его сложности.