МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ В ПРИРОДНИЧИХ НАУКАХ ТА ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ

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INTERPOLATION OF TECHNICAL MEASUREMENTS OF AUTOMATIC AND ELECTRONICS DEVICES IN MECHANOTRONIC SYSTEMS

The paper presents an algorithm for interpolation of technical measurements of automatic and electronic devices, which is performed cyclically, with a high frequency. Based on the application of the estimated function method, based on the result of a step along any controlled coordinate, an estimated function is calculated, the sign of which determines the direction of the next step. The displacements resulting from this step bring the trajectory under investigation closer to the given curve. The interpolation algorithm by the estimation function method is implemented in software or hardware, all mode operations are performed simultaneously during one period of operation.
***Keywords**: electrical signals, electronic-digital devices, digital-analog devices, discretization.*

У роботі представлено алгоритм інтерполяції технічних вимірювань пристроїв автоматики та електроніки, що виконується циклічно, з високою частотою. На основі застосування метода оцінної функції, за результатом кроку вздовж будь-якої керованої координати, обчислюється оцінна функція, знак якої визначає напрямок наступного кроку. Переміщення, що виникають в результаті цього кроку, наближають траєкторію, яка досліджується, до заданої кривої. Алгоритм інтерполяції методом оцінної функції реалізується програмно або апаратно, всі операції режиму виконуються одночасно протягом одного періоду роботи.
***Ключові слова**: електричні сигнали, електронно-цифрові пристрої, цифро-аналогові пристрої, дискретизація, інтерполяція, оцінна функція.*

Problem's Formulation

The further development of the economy of Ukraine is closely related to the wide automation and improvement of technological processes based on electronics, computer and microprocessor technology. The role of electronic and automatic devices is growing nowadays due to the widespread use of mechatronics technology.

The functioning of mechanotronic systems acts as a sequential and systematic experimental and analytical process, the effectiveness of which depends on the level of modern information technologies and decision support systems; excellence of modern technical means, mathematical models and computational methods; multifunctionality and mobility of hardware and software modeling systems.

Analysis of recent research and publications

A wide range of machine-building products, a large number of measured parameters, and the complexity of rules and algorithms make it particularly relevant to generalize the results achieved by domestic and foreign scientists in the field of mathematical modelling of complex systems, hardware and software methods and technical means of assessing the technical condition of mechanotronic objects [1—4].In this regard, great attention is traditionally paid to the development of interpolation algorithms, and today there are several interpolation methods and dozens of their versions and variants [5—7].

Formulation of the study purpose

The purpose of the research is to create a general linear interpolation algorithm for mechatronic systems, which can be modified due to discretization and quantization of information signals of dynamic characteristics according to the block principle.

Presenting main material

In modern integrated mechatronic systems, electrical signals are mainly used, which are characterized by a high speed of their processing, ease of formation and transmission over long distances, a wide range of currents and voltages, ease of conversion of electrical energy into other types (thermal, mechanical, light), etc. others The information content conveyed by these signals is modulated or encoded into their electrical or time parameters and then demodulated or decoded. This process is characterized by the transformation of physical effects on control objects (heating, movement, rotation) into forms that are convenient for visual reading (movement of the arrows of measuring devices, numbers and symbols of information panels).

Information acquisition systems are divided according to the principles of building structures (Tabl. 1) and according to the characteristics of information signals (Tabl. 2) [8].

Table 1. Classification of information systems according to the principle of building structures

Classification sign	Class	
	1	2
Availability of a special communication channel	Absent	Available
Procedure for receiving operations	Consistent	Parallel
Aggregation of the composition of the system	Aggregated	Unaggregated
Using the standard interface	Not used	Used
Availability of software-controlled computing devices	Absent	Available
Availability of information feedback loops	Opened	Compensation (single and multi-circuit systems)
Changing the speed of receiving and issuing information	No change (in real time)	With a change in speed
Signals used in the information system	Analogues	Pulse code
Structural and information redundancy	Dimensionless systems	Excessive systems
Adaptation to excessive values	Unadaptable	Adaptive

Table 2. Classification of information systems according to the characteristics of information signals

Classification sign	Classes	
	1	2
Behavior in time	Immutable	Changeable
Location in space	Concentrated	Distributed
Character of values	Uninterrupted	Discrete
Energy sign	Active	Passive
Interrelation of obstacles with input values	Independent obstacles	Obstacles that are associated with input values

In the process of formation, transmission and processing, electrical signals are subject to amplification and filtering. To eliminate distortions and protect against interference, signals are shaped by shape, amplitude, or duration. For this, electronic devices are used, which consist of electronic elements and passive electric circuits (resistors, capacitors, inductors), which are designed to connect individual electronic elements and perform independent functions of converting electrical signals.

The use of electronic-digital and digital-analogue devices allows you to perform arithmetic and logical operations, differentiation, integration and conversion operations for electrical signals according to almost any mathematical law.

Thanks to these unique features, the formation, processing and conversion of electrical signals can be carried out at a frequency of tens and hundreds of megahertz, and the signal level can be amplified from a fraction of a microvolt to hundreds of volts, and the power can be from a fraction of a nanowatt to hundreds of kilowatts [9].

Modern electronic elements of devices used in mechatronics systems are produced, as a rule, in two types:

– in the form of individual discrete components (diodes, transistors, thyristors, etc.);

– in the form of integrated circuits, in which a number of separate elements are combined in one body or in one functional unit, which is usually completed on one semiconductor crystal.

Elements of the first type are used primarily in power chains of information systems, which are usually simple in terms of circuitry, dissipate a significant amount of heat and have large dimensions. Elements of the second type are more complex in structure, perform increasingly complex functions, and contain an increasing number of separate electronic elements.

Regardless of the degree of complexity of microcircuits and the numerous functions they implement, the basis of their structure is elementary circuits, the physical principles and features of which work is more easily and effectively revealed when simulating microcircuits with the help of individual discrete electronic and electrical elements. This allows more efficient and full use of their qualities simplifying the process of setting up and monitoring their current state.

In information systems, there is a problem with processing messages that are taken from analogue sensors and have a digital form, discretization (quantization) of analogue signals is carried out. There are three types of discretization [10]:

– by time;

– by level;

– by level and time (combined).

Suppose that the information is displayed by an analog continuous function, which consists in describing the change in sensor readings over time. As a result of the next computing cycle, which is performed at the highest possible speed in the machine time scale, it is determined for which sensor commands should be issued at the current control stage. The results are stored in the buffer, which is accessed with a frequency that corresponds to the speed of changing the operating modes of the mechatronic system. In this way, machine-scale calculations are tied to real-time, the development of events which is determined by technological considerations. However, the value of the interpolation period remains fixed only during the processing of the current state, which corresponds to the given mode of operation of the mechatronic system.

When moving to the next operating mode, the value of the interpolation period must be recalculated based on the feed rate of the drive. Therefore, the interpolation process is a set of computing cycles that are continuously repeated until all information is fully processed and ends with the determination of combinations of commands issued by the control bodies.

The interpolation algorithm is performed cyclically, with a high frequency, based on the application of the estimation function method. The essence of this process is that based on the result of steps along any controlled coordinate, an estimated function is calculated. The sign of the function determines the direction of the next step. The movement resulting from the step brings the trajectory under investigation closer to the given curve [11]. All calculations are carried out in whole numbers, so-called discrete units.

Let some arbitrary curve described by the following equation be subject to interpolation

$$y_i X - x_i Y = 0\,, \tag{1}$$

where — x_i, y_i coordinates of the current point of a straight line; X, Y — personnel increments along axes Ox and Oy .

Then the evaluation function F has the form

$$F_i = y_i X - x_i Y\,. \tag{2}$$

This expression allows you to calculate the evaluation function and determine its sign, and when making a step along the axis in one discrete time, the evaluation function will have the form

$$F_{i+1} = (y_i + 1)X - x_i Y = (y_i X - x_i Y) + X = F_i + X\,.$$

Thus, the calculation of the new value of the evaluation function is based on the previous value of the evaluation function that is stored. At the same time, the initial value of the evaluation function is equal to zero, and all its subsequent values are determined only by the number of personnel increments selected from the program. The sign of the evaluation function obtained as a result of the next step determines the direction of the next step (Fig. 1).

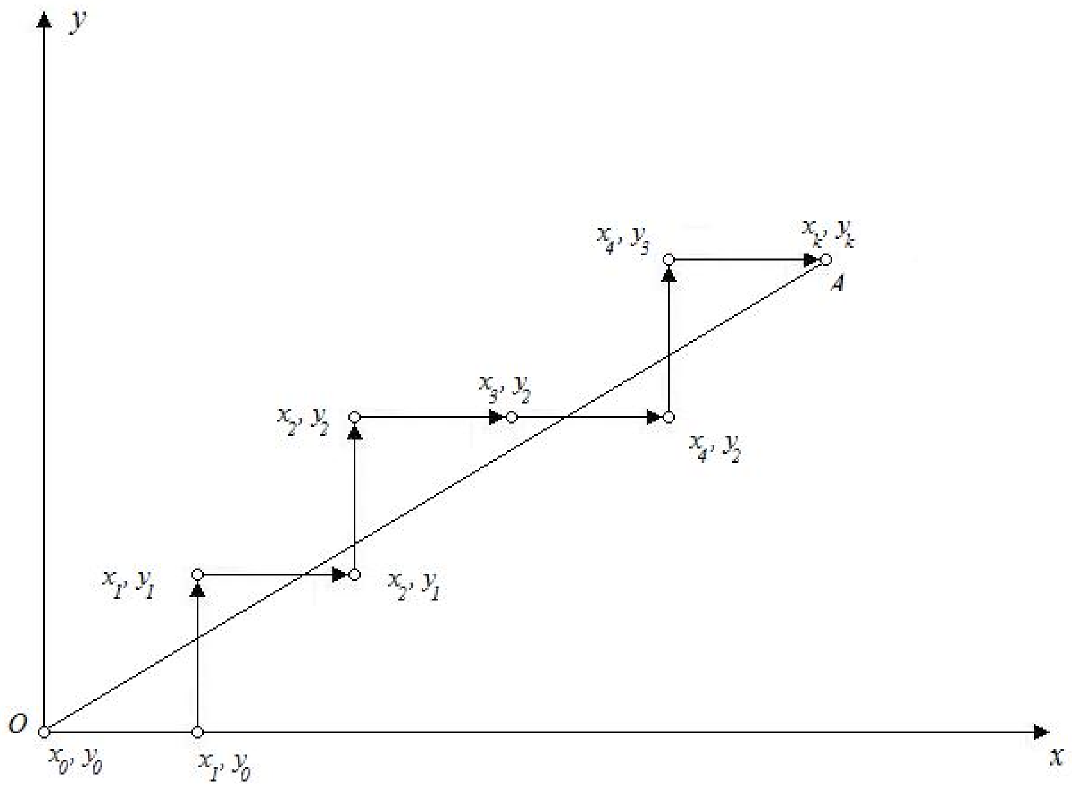

Fig. 1. Linear interpolation by the estimation function method

If the intermediate point of the interpolation trajectory is in the region $F < 0$. Then the next step of movement is performed along the axis Ox by one discret. If the intermediate point of the trajectory is in the area $F > 0$, then the next step is performed along the axis Oy .

Since the process takes place in a relative coordinate system, the beginning of the interpolated segment is always at the origin of the coordinates, while the starting point of the interpolation trajectory is in the region $F = 0$ and has coordinates $x_0 = 0; y_0 = 0$. If the line segment is located in other quadrants of the coordinate plane, then in order to apply the interpolation algorithm, it is necessary to first move to the first quadrant. The peculiarity of the algorithm is that for each current time segment, linear interpolation is carried out according to one of two possible modes (Tabl. 3) [12].

Table 3. Mode of linear interpolation by the estimation function method

№	Regime 1 ($F > 0$)	Regime 2 ($F < 0$)
1	Step along the axis Ox	Step along the axis Oy
2	$F_{i+1} = F_i - Y$	$F_{i+1} = F_i + X$
3	$x_{i+1} = x_i + 1$	$y_{i+1} = y_i + 1$
4	Audit $x_{i+1} = X$	Audit $y_{i+1} = Y$

The interpolation algorithm by the estimation function method is quite simply implemented in software or hardware, and all mode operations are performed simultaneously during one period of operation and during this time the desired operation mode must be established. The codes of the numbers contained in the register must be entered into it by shifting with the simultaneous execution of arithmetic code operations ($x_{i+1} = x_i \pm 1$), and the codes of the new value of these values x_{i+1} are entered into the register. Entering and outputting codes occur simultaneously, namely, the lower digit of the new code immediately follows the higher digit of the previous code.

For mechatronic systems, the general interpolation algorithm can be modified due to the discretization and quantization of information signals of dynamic characteristics according to the block principle, while the carrier frequency is chosen constant and the set of blocks involved in the interpolation process is determined by the orientation of the interpolation plane.

For a mechatronic system operating at a constant carrier frequency with a period T , interlock increments $\Delta x_i, \Delta y_i$ in the *i*-th cycle of interpolation are related by the following equations

$$\Delta x_i \tau - X\,T = 0\,,$$
$$\Delta y_i \tau - Y\,T = 0\,,$$

where τ — frame working time; $\Delta x_i = x_i - x_{i-1}$, $\Delta y_i = y_i - y_{i-1}$.

Compilation of interlock increments from the beginning of the frame to the *i*-th cycle of interpolation allows you to proceed to the following formulas

$$\sum_{k=1}^{i} \Delta x_k - i\frac{XT}{\tau} = 0\,, \sum_{k=1}^{i} \Delta y_k - i\frac{YT}{\tau} = 0\,, \qquad (3)$$

where $\sum_{k=1}^{i} \Delta x_k$, $\sum_{k=1}^{i} \Delta y_k$ — total movements of the reproducing trajectory of the point by coordinates X and Y from the beginning of the frame to the *i*-th cycle of the constant carrier frequency period.

If we take into account that the interpolation is carried out by whole numbers, then for the estimated functions we obtain, according to (3), the following system of equations

$$\begin{cases} N_i = \sum_{k=1}^{i} \Delta x_k - i\Delta\tilde{x} \\ M_i = \sum_{k=1}^{i} \Delta y_k - i\Delta\tilde{y} \end{cases} \qquad (4)$$

where N_i, M_i — evaluation functions along the axes Ox and Oy ; $\Delta\tilde{x} = \frac{XT}{\tau}$, $\Delta\tilde{y} = \frac{YT}{\tau}$ — average interlock increments of the corresponding coordinates, which must be worked out in each interpolation cycle.

Taking (4) into account, the control strategy for the next *i*-th cycle can be constructed as follows

$$\Delta x_i = \begin{cases} \mathrm{int}(\Delta\tilde{x}), & N_i > 0, \\ \mathrm{int}(\Delta\tilde{x}) + sign(x), & N_i < 0; \end{cases}$$

$$\Delta y_i = \begin{cases} \text{int}(\Delta\tilde{y}), & M_i > 0, \\ \text{int}(\Delta\tilde{y}) + sign(y), & M_i < 0. \end{cases} \qquad (5)$$

It follows from formula (5) that the successive increments of blocking Δx_i, Δy_i are discrete integers. Therefore, the average block increments should also be measured in discrete units, and the linear interpolation algorithm will consist of the parallel calculation of the clock increments of all coordinates for the current interpolation cycle and consists of the following actions T [13]:

– accept the previous values of the clock increments of the coordinates for the current i-th cycle;

– calculate values of evaluation functions N_i, M_i;

– with negative values of the evaluation function, adjust the previous value of the clock increment of the coordinate by adding one discrete;

– determine the number of interpolation cycles $i_{\max} = \tau/T$ and the duration of the last cycle, which may be less than the period value T;

– clock increments of the coordinates for the last cycle are determined by the formulas

$$\Delta x_{i\max} = X - \sum_{i=1}^{i_{\max}-1} \Delta x_i;$$

$$\Delta y_{i\max} = Y - \sum_{i=1}^{i_{\max}-1} \Delta y_i.$$

Conclusions

1. The scheme of linear interpolation by the method of an estimated function at a constant carrier frequency is considered a process of producing compensations at each step of the interpolation cycle in order to prevent deviations from the given trajectory of movement.

2. The interpolation trajectory runs mostly from above over the specified movement trajectory for the modified method of the evaluation function.

3. The method of the estimation function at a constant carrier frequency reproduces the specified movement trajectory more accurately compared to the function that estimates the interpolation error of only the current step.

4. The estimation functions determine the accumulated interpolation error more accurately compared to the function that estimates the interpolation error of the current step only.

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ІНТЕРПОЛЯЦІЯ ТЕХНІЧНИХ ВИМІРЮВАНЬ ПРИСТРОЇВ АВТОМАТИКИ ТА ЕЛЕКТРОНІКИ В МЕХАНОТРОННИХ СИСТЕМАХ

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Реферат

У сучасних інтегрованих механотронних системах в основному використовуються електричні сигнали, які характеризуються високою швидкістю їх обробки, легкістю формування і передачі на великі відстані, широким діапазоном струмів і напруг, легкістю перетворення електричної енергії в інші види (теплові, механічні, світлові) тощо. Інформаційний вміст, що передається цими сигналами, модулюється в їхні електричні або часові параметри, а потім демодулюється або декодується. Цей процес характеризується перетворенням фізичних впливів на об'єкти управління в форми, зручні для візуального зчитування.

У роботі представлено алгоритм інтерполяції технічних вимірювань автоматичних та електронних пристроїв, який виконується циклічно, з високою частотою. На основі застосування методу оціночної функції за результатом кроку по будь-якій контрольованій координаті розраховується оціночна функція, знак якої визначає напрямок наступного кроку. Зсуви, що виникають в результаті цього кроку, наближають досліджувану траєкторію до заданої кривої. Алгоритм інтерполяції методом функції оцінювання реалізований програмно або апаратно, всі режимні операції виконуються одночасно протягом одного періоду роботи.

Схема лінійної інтерполяції методом оціночної функції при постійній несучій частоті розглядається як процес здійснення компенсацій на кожному кроці циклів інтерполяції з метою запобігання відхилень від заданої траєкторії руху.

Для механотронних систем загальний алгоритм інтерполяції можна модифікувати за рахунок дискретизації та квантування інформаційних сигналів динамічних характеристик за блочним принципом, при цьому несучу частоту вибирають постійною, а набір блоків, що беруть участь у процесі інтерполяції, визначають за орієнтація площини інтерполяції.

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