Rationalization of the process of improving the quality of spatial control systems for unmanned aerial vehicle groupings

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Abstract: The article substantiates that the methodological basis for improving the quality of spatial management systems for unmanned aerial vehicle groupings, as part of the concept of monitoring and improving the quality of software and hardware systems for managing heterogeneous robotic aircraft groups and the methodological basis for qualimetric requirements for software and hardware systems for managing unmanned aerial vehicle groupings, allow to achieve rationalization of the development process and improving complexes spatial quality control heterogeneous robotic aviation groupings. Possibilities of reducing time and labor costs for the process of forming and improving the quality of software and hardware systems for managing groups of unmanned aerial vehicles are shown. It is mathematically justified that the use of one integrated model of data structures for software and hardware complexes for managing unmanned aerial vehicle groupings while streamlining the process of improving the quality of spatial control systems for unmanned aerial vehicle groupings based on the proposed methodological foundations leads to an objective saving of resources for the development of these complexes.

1. Introduction
The concept of monitoring and improving the quality of software and hardware systems for controlling heterogeneous robotic aviation groups and the methodological basis for qualimetric requirements for software systems for managing groups of unmanned aerial vehicles (UAV) form the methodological basis for improving the quality of spatial control systems for these groups of unmanned aerial vehicles. Such methodological foundations are not an end in themselves of scientific knowledge in qualimetry and act as a theoretical basis for obtaining applied methods, methods of monitoring and improving the quality of software and hardware complexes for controlling groups of unmanned aerial vehicles. Their practical application is primarily aimed at rationalizing the development process and improving the quality of spatial control systems for unmanned aerial vehicle groups. Accordingly, the effect of their use can be shown precisely as a result of the rationalization of this process.

2. The main provisions
To theoretically substantiate the effect of the application of the proposed methodological foundations, it is necessary to model the process of developing and improving the quality of spatial control systems for UAV groupings, using the logical and mathematical way: we assume that the software-hardware
complex for managing groups of unmanned aerial vehicles consists of $Q$ functionally independent components.

Let for each component $q$, which $q \in Q$, fixed families (indexed sets) are defined, corresponding to the individual elements of the target function of the component of the hardware-software complex, i.e. families of all elements of the functional that are realized by the $q$ component in the course of its purposeful application are defined:

$$\Phi_q = \{\varphi_q^1, \varphi_q^2, \ldots, \varphi_q^l \}.$$  

(1)

where: $l$ is the total number of all elements of the functional.

In turn, a family of all specific data structures of support (representation, presentation) of functional elements implemented by component $q$ in the course of its purposeful application is also specified:

$$D_q = \{d_q^1, d_q^2, \ldots, d_q^k \}.$$  

(2)

where $k$ is the total number of all specific data structures of these functional elements.

Accordingly, from the relations (1) and (2) it follows that each functional element implemented by the component of the hardware-software complex $q$ can be associated with a specific data structure of the representation of the current functional element. This mapping allows to specify a mathematical display:

$$f_q : \Phi_q \rightarrow D_q,$$  

(3)

which, to each element of the functional implemented by the component of the hardware-software complex $q$, associates a specific data structure of the representation of this functional element. Such a mapping is characterized by the property:

$$\forall \varphi_q^a \in \Phi_q \exists d_q^b \subset D_q, \ n p u \ a \in \{1..l\}, \ b \in \{1..k\}, \ q \in Q.$$  

(4)

At the same time, several specific data structures can be associated with a single element of the functional $\varphi_q^a$, i.e. there is no one-to-one (bijection) in the map (3). Then, surjection of the mapping (3) will consist in mapping to each unit element of the functional $\varphi_q^a$ the following two options:

- the subfamily of specific data structures of the representation of the a-th element of the functional $d_q^a$ includes one member, i.e. each functional element represents only one specific data structure;
- a subfamily of specific data structures $d_q^a$ includes $\mu$ members where $\mu \leq l$, i.e. each element of the functional represents several specific data structures, but not more than the total number of the indicated functional elements, that is:

$$\mu \leq l.$$  

(5)

It is also possible to simulate the totality of all the specific structures of the input data needed by the component of the hardware-software complex $q$ during the implementation of its functionality, as the corresponding mathematical family:

$$I_q = \{i_q^1, i_q^2, \ldots, i_q^m \},$$  

(6)

where $m$ is the total number of specific data structures of the input data stream.

For family (6), it follows that each current element of functionality implemented by the $s$ -th software component is associated with the necessary specific structure of input data. Mathematically, this means
that a surjective mapping is given, which, associates with each element of the functionality implemented by the component of the hardware-software complex \( q \), the specific structure of the input data

\[
 f_q : \Phi_q \rightarrow I_q, \tag{7}
\]

The indicated mapping (7) is characterized by the property:

\[
 \forall \varphi_q^a \in \Phi_q \exists I_q^b \subset I_q, \text{ nuu } a \in \{1..I\}, b \in \{1..m\}, q \in Q. \tag{8}
\]

At the same time, several specific data structures can be associated with a single element of the functional \( \varphi_q^a \), i.e. surjection of the mapping (7) will consist in associating with each unit element of the functional \( \varphi_q^a \) the following two options:

- the subfamily of specific data structures of the representation of the \( a \)-th element of the functional \( I_q^a \) includes a single member, i.e. each element of the functional represents only one specific structure of the input data;
- a subfamily of specific input data structures \( I_q^a \) includes \( \mu \) members. This means that each element of the functional is associated with several specific structures of input data, but no more than the total value of all specific data structures, that is:

\[
 \mu \leq m. \tag{9}
\]

Assuming that for the component of the hardware-software complex \( q \) digital information is required from the component \( p \), one can conclude: the associated specific structure of the output data \( d_p^j \) of the component \( p \) must strictly correspond to the specific structure of the input data \( i_q^g \) of the component of the hardware-software complex \( q \), which can be mathematically shown as:

\[
 d_p^j \equiv i_q^g. \tag{10}
\]

The above-described set-theoretic model for considering functionally independent components of software and hardware complexes for controlling groups of unmanned aerial vehicles allows us to assume that the total number of families of specific data structures \( R \) is determined by multiple summation (combining) of families of specific structures of input and output data, i.e.

\[
 R = I \cup D. \tag{11}
\]

In turn, the family of complex specific data structures \( \overline{R} \) is determined by multiple multiplication (intersection) of families of specific structures of input and output data, i.e.

\[
 R = I \cap D. \tag{12}
\]

At the same time, the set of families of specific structures of input and output data itself can be divided into 3 disjoint subsets:

- specific input data structures of the entire hardware and software complex - \( A \);
- specific structures of the output data of the entire software and hardware complex - \( C \);
- specific data structures for the exchange of digital data of components within the hardware-software complex - \( B \).

For the specified classification of the types of specific data structures in the software and hardware complexes for controlling the groupings of unmanned aerial vehicles, the following relationships will be performed, presented in the form of logical-multiple expressions:

\[
 R = I \cup D = A \cup B \cup C; \tag{13}
\]

\[
 \overline{R} = I \cap D = B; \tag{14}
\]
Each current element of functionality, the function of the component part of the software and hardware complex provides another component with a specific data structure for representing transmitted digital content that, based on the accepted logical-multiple notation and relations (1) - (15), will mean

$$\forall q^a \in \Phi \exists d^b_q \subset D_q.$$  

(16)

To convert digital data to a format used in the current component of the hardware-software complex, i.e. to achieve compliance with the current specific data structure, a certain time is spent

$$t_i = f(d_i), \forall d_i \in D_q.$$  

(17)

Then, the total time spent on providing data as an integral part of the hardware-software complex is the sum of the transformations of the corresponding digital data to each specific data structure, which in a formal form is representable as

$$T_q^u = \sum_{i=1}^{n} t_i,$$  

(18)

where \(n\) is the total number of specific data structures associated with the functionality element \(q^a\).

When streamlining the process of creating, shaping and improving the quality of spatial management systems for unmanned aerial vehicle groups based on the proposed methodological foundations, the conversion of all specific data representation structures to one of their formats will be spent exclusively on the initial, first conversion, while the remaining specific data structures will be obtained due to duplication of the initial, which means

$$T_q^u = t_0.$$  

(19)

For a component of software and hardware complexes \(q\), the time used to convert digital information to the required specific data structures is equal to the total result of all conversions of digital information to the required specific data structure of each element of the functionality of the current component of the software and hardware complex, i.e.

$$T_q = \sum_{i=1}^{l} T^u_q,$$  

(20)

where \(l\) is the number of elements of functionality implemented by the current component of the hardware-software complex.

Accordingly, for the software and hardware complexes for controlling the groups of unmanned aerial vehicles, in general, the total time used to convert digital information to the required specific data structures is the sum of the time values for converting digital information to the required specific data structures for each current component in the whole complex:

$$T = \sum_{q=1}^{Q} T_q,$$  

(21)

where \(Q\) is the total number of components in the hardware-software complex for controlling the groups of unmanned aerial vehicles.

Then it becomes possible to come to the conclusion about reducing time and labor costs for the process of forming and improving the quality of software and hardware systems for controlling groups of unmanned aerial vehicles while rationalizing this process on the basis of the proposed methodological foundations. The widespread use of the proposed concept of monitoring and improving the quality of software and hardware complexes for controlling groups of unmanned aerial vehicles in conjunction with the methodological basis of the relevant requirements objectively leads to an increase in the temporal productivity of the process of improving the quality of these complexes. Such an effect in
rationalizing the indicated process is theoretically derivable and justified, since when the total time for converting digital information to each current specific data structure of each functional element of each component of the software and hardware complexes for controlling groups of unmanned aerial vehicles is longer than the total time for converting digital information to generalized, a harmonized and integrated ontology (i.e., a single, integrated model of data structures in software and hardware complexes) for all specific data structures for each current element of the functionality of each component of the complex is described strict inequality:

\[ \sum_{q=1}^{Q} \sum_{a=1}^{l} \sum_{i=1}^{n} t_{qa} > \sum_{q=1}^{Q} \sum_{a=1}^{l} t_{qa}^* \]  

(22)

where: \( Q \) is the total number of components in the software and hardware complexes for controlling the groups of unmanned aerial vehicles;

\( l \) – is the number of elements of functionality implemented by the current component \( q \),

\( n \) –the total number of specific data structures \( q_a \) that are mapped to a functional element \( q \).

No less clearly we can trace the effect in rationalizing the process of improving the quality of spatial management systems for unmanned aerial vehicle groupings through the application of the proposed methodological foundations, if we analyze the savings achieved in the development of software and hardware systems for managing unmanned aerial vehicle groups of material resources (finance, material reserves, etc.).

Suppose that for the development of issues of functional integrity and information and technical connectivity of the components of software and hardware systems for controlling groups of unmanned aerial vehicles, a certain amount of financial and other material resources has been assigned, i.e., speaking generally, resource \( S \). The volume of the resource is finite and unchanged, i.e.

\[ S = \text{const}. \]  

(23)

Objectively specified resource should be distributed as follows:

- on the development of elements of functionality implemented by the hardware-software complex – \( S_{\Phi} \);
- to develop specific data structures – \( S_R \).

The allocated resource for the development of specific data structures \( S_R \) is conditionally divided into development sub-resources for each of the types of families of specific input and output data structures according to (13) - (15). This is formally representable as:

\[ S_R = S_A + S_B + S_C. \]  

(24)

Then, according to (24), any of the sub-resources can be represented as the total result of resource expenditures for the development of each of the specific data structures included in the corresponding subset, i.e.:

a) the expenditure of resources on the development of elements of applied and systemic functionality, implemented by the software-hardware complex for managing groups of unmanned aerial vehicles, there is an additive convolution:

\[ S_{\Phi} = \sum_{i=1}^{l^{'}} S_{\Phi_i}, \]  

(25)

where \( l \) is the total number of elements of functionality implemented by the hardware-software complex for controlling the groups of unmanned aerial vehicles;

b) the expenditure of resources on the development of specific input data structures in the hardware-software complex for managing groups of unmanned aerial vehicles, we also represent an additive convolution:
\[ S_A = \sum_{i=1}^{m} s_a, \quad (26) \]

where \( m \) is the total number of specific input data structures in the hardware-software complex for controlling the groups of unmanned aerial vehicles;

c) the expenditure of resources on the development of specific structures of the output data in the hardware-software complex for managing groups of unmanned aerial vehicles, we also present as an additive convolution:

\[ S_c = \sum_{i=1}^{D} s_c, \quad (27) \]

where \( D \) is the total number of specific structures of the output data in the hardware-software complex for controlling the groups of unmanned aerial vehicles;

d) the expenditure of resources on the development of specific data structures for the exchange of digital data of components within the hardware and software complex can be formally described as:

\[ S_B = \sum_{i=1}^{n} s_b, \quad (28) \]

where \( n \) is the total number of specific data structures of the constituent parts in the hardware-software complex for controlling the groups of unmanned aerial vehicles.

From relations (24) - (28), it is easy to see that the conversion of all types of specific data structures of components as part of software and hardware systems for managing groups of unmanned aerial vehicles to a single ontology (to a single integrated model of data structures in a software and hardware complex) makes it possible having developed only one integrated and harmonized data structure, having spent the amount of the total resource, implement all the others without the expense of resources, by repeating the primary and integrated data structure. Therefore, when rationalizing the process of forming and improving the quality of software and hardware complexes for managing unmanned aerial vehicle groupings on the basis of the proposed methodological foundations, the total resource costs will be equal to the costs of developing one integrated model of data structures, i.e.

\[ S_B = s_b. \quad (29) \]

It can also be shown that the use of one integrated model of data structures for software and hardware complexes for controlling unmanned aerial vehicle groupings while streamlining the process of improving the quality of spatial control systems for unmanned aerial vehicle groupings based on the proposed methodological foundations leads to an objective saving in the assigned resource for the development of this complex. Such an effect in the rationalization of this process is theoretically derivable and justified, since when the total resource for the development of all specific data structures for the exchange of digital information between components within the hardware-software complex for controlling groups of unmanned aerial vehicles is theoretically justified more than the resource for developing an integrated model data structures in the hardware and software complex, there will be a steady and irreversible inequality

\[ S_B \succ s_b. \quad (30) \]

3. Conclusion

Thus, the theoretical study led to the conclusion that the methodological basis for improving the quality of spatial control systems of the indicated groups of unmanned aerial vehicles, as part of the concept of monitoring and improving the quality of software and hardware systems for controlling heterogeneous robotic aviation groups and the methodological basis of qualimetric requirements for software unmanned aerial vehicle grouping control equipment allow to achieve an efficient rationalization of the process of development and improvement of the quality management systems of spatial heterogeneous robotic aviation groupings.
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