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Ensuring the Efficiency of the Hazardous Biotronics Technologies

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Introduction

The efficiency evaluation of many biotronic (interaction of biologic and electronic objects, BO and EO) technologies (BT) [1] can be performed by using economic parameters, without considering the technical properties (e.g., task accomplishment probability [2]). The values of these parameters are not very high and therefore it can be dispensed with particular measures required to improve the technologies mentioned above.

However, when synthesizing and controlling some of the BT technologies (especially devices of animal BT and processes inside these devices), it is usually required to seek its maximum efficiency, despite the costs of material and time. For this purpose the methods for ensuring the efficiency of hazardous BT technologies (HT) are needed. Technologies are considered as hazardous when their failures or disturbances may lead to severe events, such as human death or biologic catastrophes.

The purpose of this investigation is to determine methods by which it would be possible to increase the task accomplishment probabilities of HT at the most, and the task of investigation is to create the method for the evaluation of efficiency of these technologies.

Methods for efficiency improvement

High efficiency of HT can be ensured the following ways:

1. Significantly increasing the reliability of BT electronic measures (devices and processes): using the most reliable components; providing component redundancy and increasing the structural (logical) reliability of the BT.
2. Providing high persistence of electronic devices [2]: their functional inertia; non-depreciation of their results; abundance (excess) of their features, etc.
3. Planning the monitoring of the early disturbance (failure) indications [4] and the prevention of the catastrophes (by ensuring the control of reliability during exploitation).
4. Organizing the continuous control of HT implementation, warning about a planned inappropriate operation beforehand, eliminating it and replacing by more efficient one.

The positive effect using the first technique can be achieved by ensuring the explicitness, clarity, unambiguity, unification, standardization, visualization, surveillance and other features of HT.

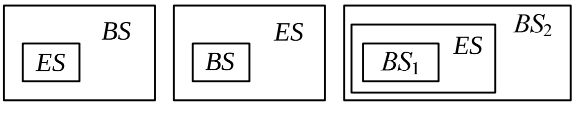
When increasing the efficiency by using the second technique, it is necessary to ensure the flexibility, modality, excess of the module execution time resources, dynamic redundancy of technologies [2] and similar features.

Entire complexes of control and regulation measures are used [5] during the control of HT reliability.

Efficiency of continuous control of HT management depends on the degree of modality of this technology, the integrality of control operations, multiplexity, reliability and other factors. We will discuss several options further.

The influence of HT modularity and its control integrality on the task accomplishment probability

Electronic systems (ES) are very often designed in order to control the biologic systems (BS) from the EO to improve HT. Both of these systems are integrated (ensuring their common purpose and central control). In this manner integrated biotronic systems (IBTS) are formed. During the integration the systems with the priorities of objectives of BS (Fig. 1, a) and ES (Fig. 1, b) can be created.



a) b) c)

Fig. 1. Schemes of integration of HT systems

In case of Fig. 1, a, ES functions are determined by the state of BO and both systems seek for the optimal or acceptable state of this object. For example, the heart pace regulation system operates in this way: when the heart rhythm becomes unstable, the ES (stimulation system) is activated, which attempts to restore the desired rhythm of the heart. When it is restored, the system is deactivated.

The IBTS of the type indicated in Fig. 1, b control (for example) the weapons of the plane: when the pilot directs his sight on to the aim, the gun is positioned; in this case the highest probability of the successful hit is the objective of IBTS. Using this scheme eye-controlled computer cursor IBTS system can be created.

In medicine a system "medic → ES → patient" is used very often (Fig. 1, c). Here the priority is also attributed to the state of BO (patient) – to the objectives of BS2. Consequences of operation of such IBTS condition the fact that it is attributed to the group of HT. The control system of syringe infusion pumps operates in this manner. The ES efficiency (task accomplishment probability) inside of it can be increased by using the first three methods. The situation when ES already operates efficiently, but there are still reserves available for its improvement is often. Most of the risk is conditioned by BS_1 HT. Third and fourth methods are more suitable in order to increase their efficiency. It is determined by HT modularity and integrality of its control.

In this case HT consists of n modules (M_1, …, M_n), and their task accomplishment probabilities $\{P_{Ui}\}$ (i=1, …, n) are same and equal to P_{Ui}, and the efficiency (task accomplishment probability) of control of any j-th integrality is ρ_i^j (Fig. 2). Such situation is formed when the integral control (K_I) is practically of the same purpose and size as the entirety of differential controls (K_1, ..., K_n), which are equivalent to it and their efficiency value is the same. In case of differential HT control (it is indicated by the dotted line in Fig. 2) the overall tasks accomplishment probability of entire technology is

$$P_{Ub} = \left[1-\left(1-P_{Ui}\right)\left(1-\rho_i\right)\right]^n . \tag{1}$$

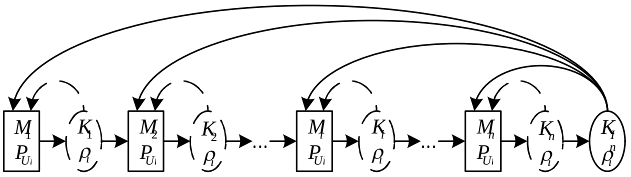


Fig. 2. Cases of HT control

In case of integral control the overall tasks accomplishment probability is

$$P_{Ub}^1 = \left[1-\left(1-P_{Ui}^n\right)\left(1-\rho_i^n\right)\right] . \tag{2}$$

The ratio of these probabilities is

$$K = \frac{P_{Ub}}{P_{Ub}^{(1)}} . \tag{3}$$

It shows how much the differential control is better if compared to integral.

After selecting n=3 for calculations and by varying the values of P_{Ui} and ρ_i, we determine the modules of HT with various efficiencies and influence of their control technologies on the general task accomplishment probability.

The results of calculation are shown in Table 1. It can be seen from Table 1, that the differential control in all analyzed cases is more efficient than integral and the less the value of P_{Ui} is, the more efficient it is in respect of the second one. The influence of differential control efficiency on the value of P_{Ub} can be illustrated by the following ratios:

$$A_1 = \frac{P_{Ub}\left(\rho_i = 0{,}8\right)}{P_{Ub}\left(\rho_i = 0{,}0\right)} \tag{4}$$

and

$$A_2 = \frac{P_{Ub}\left(\rho_i = 0{,}99\right)}{P_{Ub}\left(\rho_i = 0{,}0\right)} . \tag{5}$$

The values of these ratios under different values of P_{Ui} are plotted in Fig. 3.

Table 1. Comparison results of differential and integral control

No.	P_{Ui}	ρ_i	P_{Ub}	$P_{Ub}^{(1)}$	K
1	0.7	0.0	0.343	0.343	1.0
2	0.7	0.8	0.830584	0.679384	1.2225545
3	0.7	0.9	0.912673	0.821959	1.1103631
4	0.7	0.99	0.9910269	0.9804865	1.0107501
5	0.8	0.0	0.512	0.512	1.0
6	0.8	0.8	0.8493465	0.761856	1.1148386
7	0.8	0.9	0.941192	0.867752	1.0846324
8	0.8	0.99	0.9940119	0.985506	1.0086309
9	0.9	0.0	0.729	0.729	1.0
10	0.9	0.8	0.941192	0.867752	1.0846324
11	0.9	0.9	0.970299	0.926559	1.0472069
12	0.9	0.99	0.9970029	0.9919511	1.0050927
13	0.99	0.0	0.970299	0.970299	1.0
14	0.99	0.8	0.9940119	0.985506	1.0086309
15	0.99	0.9	0.9970029	0.9919511	1.0050927
16	0.99	0.99	0.9997	0.9991179	1.0005826

It can be seen from Fig. 3 that the fourth method of HT efficiency improvement is especially efficient when the task accomplishment probabilities of the modules are relatively small. This is often characteristic to BS_1. Then the influence of efficiencies of control technologies on the efficiency of entire HT is more significant. It is advisable to increase the level of HT modularity.

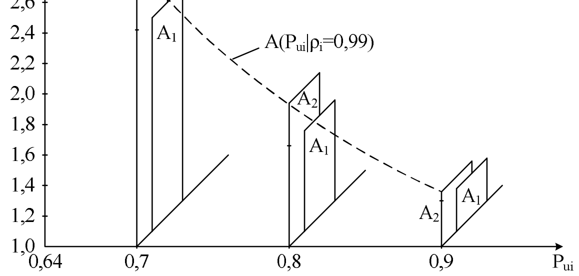


Fig. 3. Influence of differential control efficiency on the efficiency of HT

As the control of BS_1 HT is performed during entire time period of function implementation, several (for example, m) control variants (operations) with different efficiencies ({ ρ_j } (j=1, …, m) can be used. Such control variant can be illustrated by the scheme presented in Fig. 4.

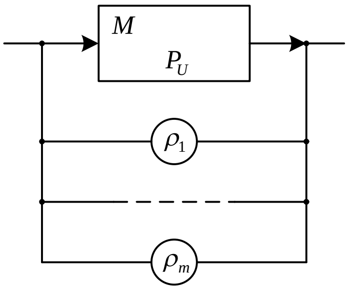


Fig. 4. Scheme of non-dispersed HT control

In this case

$$P_{Ub}^{(1)} = 1 - \left(1 - P_U\right)\prod_{j=1}^{m}\left(1 - \rho_j\right) \ . \qquad (6)$$

When technologies of separate HT parts are inter-independent and provide equal efficiency, then the scheme shown in Fig. 5 will be obtained by dividing it into two parts (n=2).

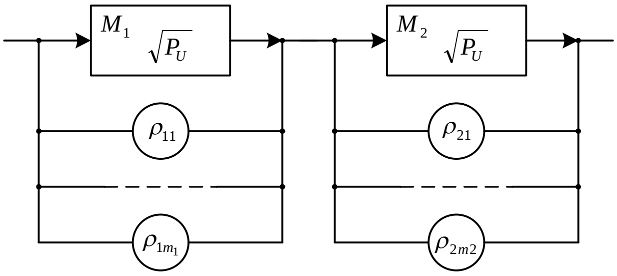


Fig. 5. Scheme of differential control of HT consisting of two modules

General efficiency of such HT is

$$P_{Ub}^{(2)} = \left[1 - \left(1 - \sqrt{P_U}\right)\prod_{j=1}^{m_1}\left(1 - \rho_{1j}\right)\right] \cdot$$
$$\cdot \left[1 - \left(1 - \sqrt{P_U}\right)\prod_{j=1}^{m_2}\left(1 - \rho_{2j}\right)\right] . \qquad (7)$$

After increasing the number of modules we would receive

$$P_{Ub}^{(n)} = \prod_{I=1}^{n}\left[1 - \left(1 - \sqrt[n]{P_U}\right)\prod_{j=1}^{m_I}\left(1 - \rho_{Ij}\right)\right] . \qquad (8)$$

When the efficiency of any I-th module (M_s) is

$$P_{U_{M_s}} \neq \sqrt[n]{P_U} \ , \qquad (9)$$

then

$$P_{Ub}^{(n)} = \prod_{I=1}^{n}\left[1 - \left(1 - P_{U_{M_s}}\right)\prod_{j=1}^{m_I}\left(1 - \rho_{Ij}\right)\right] . \qquad (10)$$

The scheme indicated in Fig. 6 could be formed by combining the combinations of differential and integral controllers.

The following notations are used in Fig. 6: M_{i1} – the 1st module of the i-th group of HT modules; $\rho_{i1_{m_{i1}}}$ – the efficiency of the m_{i1} control method of the 1st module of the i–th group of modules; D – number of module groups; A, B and C – numbers of modules in 1st, i–th and D–th groups; K – full number of methods of integral control; ρ_{I_K} – efficiency of K–th full integral control; F, G and H – numbers of partial integral control methods of the 1st, i–th and D–th groups of modules. General task accomplishment probability of HT with the combined control

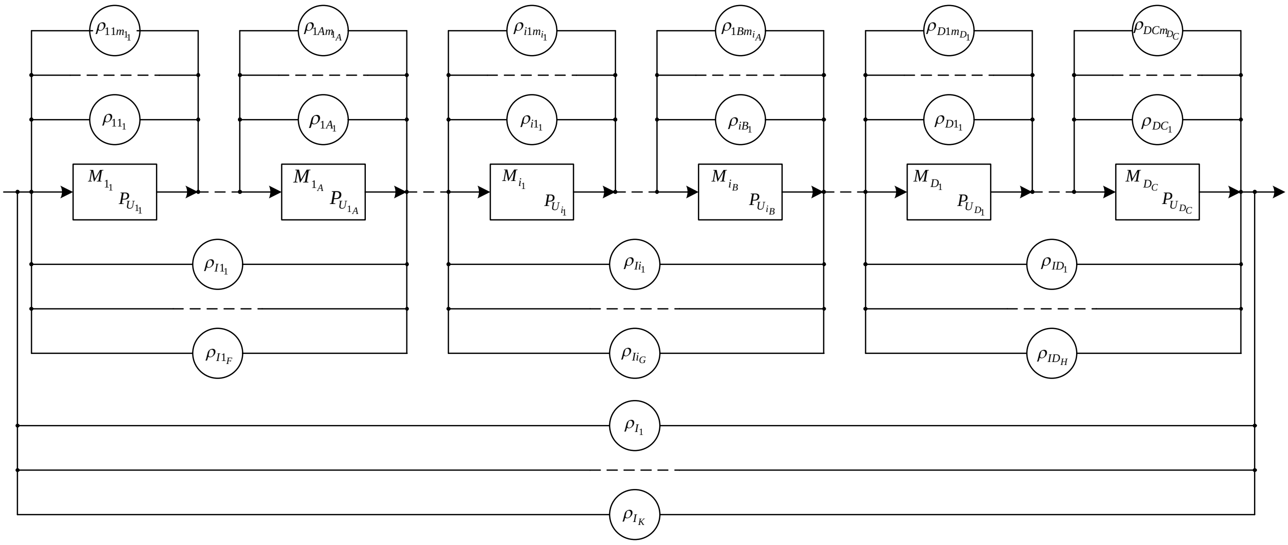


Fig. 6. Scheme of combinations of differential and integral HT controllers

$$P_{Ub}^{(K)} = 1 - \left\{ 1 - \prod_{Z=1}^{D} \left[1 - \left\{ 1 - \prod_{e=1}^{m_{id}} \left[1 - \left(1 - P_{Uie}\right) \prod_{j=1}^{m_{ie}} \left(1 - \right.\right.\right.\right.\right.$$

$$\left.\left.\left.\left.\left. - \rho_{iej}\right)\right]\right\} \prod_{b=1}^{m_{Ii}} \left(1 - \rho_{Iib}\right)\right]\right\} \prod_{g=1}^{K} \left(1 - \rho_{Ig}\right); \qquad (11)$$

here m_{id} – number of modules in *i*–th module group; P_{Uie} – task accomplishment probability (without control) of the *e*–th module of the *i*–th module group; m_{id} – number of control methods of the *e*–th module of the *i*–th module group; ρ_{ie_j} – efficiency of the *j*–th control method of the *e*–th module of the *i*–th group; m_{Ii} – number of partial integral control methods of the *i*–th group of modules; ρ_{Iib} – efficiency of the *b*–th partial integral control method of the *i*–th group of modules.

It does not need to be proved that

$$P_U < P_{Ub}^{(1)} < P_{Ub}^{(2)} < \ldots < P_{Ub}^{(n)} < P_{Ub}^{(K)}. \qquad (12)$$

Application of majoritarian control for the improvement of HT efficiency

When the aim of the control operations is to determine if the technologies of HT modules were performed correctly (“Yes” or “No”) and it is possible to sanction their implementation, then the scheme of the combined control becomes similar to the part of Fig. 7 indicated by continuous lines [6].

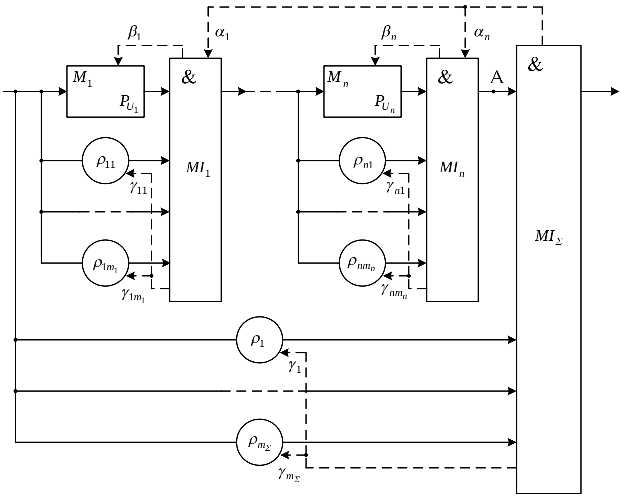


Fig. 7. Sheme of the majoritarian control of combined HT

In this scheme: MI_1, MI_n and MI_Σ – cybernetic devices, sanctioning the implementation of separate HT modules and the entire technology; m_1, m_n and m_Σ – numbers (odd) of the control variants of the first, *n*–th modules and entire HT; ρ_{11}, ρ_{1m1}, ... – efficiencies of these variants.

The first HT module (after its preparation) will be allowed to implement with probability

$$P_{UM1} = P_{U1} \cdot P_{MI_1} \left[\prod_{j=1}^{m_1} \rho_{1j} + \sum_{s=1}^{m_1} \left(1 - \rho_{1s}\right) \prod_{\substack{j=1 \\ j \neq s}}^{m_1} \rho_{1j} + \right.$$

$$+ \sum_{s=1}^{m_1 - 1} \sum_{\substack{v=2 \\ s<v}}^{m_1} \left(1 - \rho_{1s}\right)\left(1 - \rho_{1v}\right) \prod_{\substack{j=1 \\ j \neq s \\ j \neq v}}^{m_1} \rho_{1j} +$$

$$+ \sum_{s=1}^{m_1 - 2} \sum_{\substack{v=2 \\ s<v<e}}^{m_1 - 1} \sum_{e=3}^{m_1} \left(1 - \rho_{1s}\right)\left(1 - \rho_{1v}\right)\left(1 - \rho_{1e}\right) \prod_{\substack{j=1 \\ j \neq s \\ j \neq v \\ j \neq e}}^{m_1} \rho_{1j} + \ldots +$$

$$+ \sum_{s=1}^{\frac{m_1+1}{2}} \sum_{\substack{v=2 \\ s<v<\ldots<z}}^{\frac{m_1+1}{2}+1} \ldots \sum_{\frac{m_1-1}{2}}^{m_1} \left(1 - \rho_{1s}\right)\left(1 - \rho_{1v}\right) \ldots \left(1 - \rho_{1z}\right) \times$$

$$\left. \times \prod_{\frac{m_1-1}{2} \left\{ \substack{j=1 \\ j \neq s \\ j \neq v \\ j \neq e \\ \ldots \\ j \neq z} \right.}^{m_1} \rho_{1j} \right]; \qquad (13)$$

here P_{MI_1} – task accomplishment probability of the MI_1 cybernetic device. Task accomplishment probabilities of other modules (with control) can be calculated analogically. In result of differential control at the point A (Fig. 7) the following task accomplishment probability will be obtained

$$P_{UD} = \prod_{i=1}^{n} P_{UMi}; \qquad (14)$$

here P_{UMi} – task accomplishment probability of the *i*–th module (with control). By additionally using the integral control, in which the separate methods have efficiencies $\{\rho_j\}$ (j=1, …, m_Σ), and task accomplishment probability of cybernetic device MI_Σ is P_{MI_Σ}, the overall HT task accomplishment probability is achieved

$$P_{Ub} = P_{UD} \cdot P_{MI_\Sigma} \left[\prod_{j=1}^{m_\Sigma} \rho_{1j} + \sum_{s=1}^{m_\Sigma} \left(1 - \rho_{1s}\right) \prod_{\substack{j=1 \\ j \neq s}}^{m_\Sigma} \rho_j + \ldots + \right.$$

$$+ \sum_{s=1}^{\frac{m_\Sigma+1}{2}} \sum_{\substack{v=2 \\ s<v<\ldots<z}}^{\frac{m_\Sigma+1}{2}+1} \ldots \sum_{z=\frac{m_\Sigma-1}{2}}^{m_\Sigma} \left(1 - \rho_{1s}\right) \ldots \left(1 - \rho_{1z}\right) \times$$

$$\left.\times \prod_{\frac{m_\Sigma-1}{2}\begin{cases} j=1\\ j\neq s\\ \dots\\ j\neq z\end{cases}}^{m_\Sigma} \rho_j \right]. \qquad (15)$$

This is one more way to increase the HT efficiency. Technically it can be done by using the comparison of tasks and variants prepared for implementation, which are provided for HT modules (stages) (for example, in personal computer), or by using other methods of control [7].

It can be seen from the presented material, that:

1. HT comprises a part of BT technologies; input of material and time resources is not very important when implementing them.
2. Efficiency of such technologies can be increased by using four methods mentioned above. The improvement of control efficiency of HT performance is one of the most relevant topics.
3. It can be seen from the example presented, that the differential HT control can provide higher efficiency compared to the integral one. This difference is particularly obvious when task accomplishment probabilities of separate modules are small and the efficiency of control methods is limited.
4. The selected majoritarian control of HT stages is one of the possible ways to increase the efficiency of some of HT.
5. Often (but not always) when implementing the HT (Fig. 1, c) and using the priority of BS_2 objectives, there is also a possibility to control the functions of BS_1, but the efficiency of this control chain is the object for the further investigations.

Management of HT modules and majoritarian control

Assume that the feedback connections are planned in the scheme of majoritarian control (dotted lines in Fig. 7). That means that cybernetic devices (MI_1, ..., MI_n and MI_Σ) not only compare the results of application of various control methods, but also perform their analysis (by using or not using their artificial intelligence measures), accumulate experience, and also dynamically manage HT modules and their control methods. These connections are also characterized by their efficiencies (task accomplishment probabilities): $\alpha_1,\dots,\alpha_n$; $\beta_1,\dots,\beta_n$; $\gamma_{11},\dots,\gamma_{1m_1}$; ...; $\gamma_{n1},\dots,\gamma_{nm_n}$; and $\gamma_1,\dots,\gamma_{m_\Sigma}$. After self-regulation of control mode, the task accomplishment probability of any i–th module (M_i) is

$$P_{Ui}^{(1)} = 1-\left(1-P_{Ui}\right)\left(1-\beta_i\right)\left(1-\alpha_i^{(1)}\right); \qquad (16)$$

efficiency of any j–th control method of this module is

$$\rho_{ij}^{(1)} = 1-\left(1-\rho_{ij}\right)\left(1-\gamma_{ij}\right)\left(1-\alpha_{ij}\right) \qquad (17)$$

and the efficiency of i–th cybernetic device when performing the majoritarian functions

$$P_{MIi}^{(1)} = \left(1-P_{MIi}\right)\left(1-\alpha_i\right); \qquad (18)$$

here $\alpha_i^{(1)}$ – efficiency of control carried out from MI_Σ in respect of the i–th module; α_{ij} – efficiency of control carried out from MI_Σ in respect of j–th control method of the i–th module. After substituting indexes in formula (13) in respect of i–th module and replacing P_{Ui}, P_{MIi} and ρ_{i1}, ..., ρ_{ij}, ..., ρ_{im_i} with $P_{Ui}^{(1)}$, $P_{MIi}^{(1)}$ and { $\rho_{ij}^{(1)}$ } (j=1, …, m_i) values, we will be able to calculate another value of P_{UMi} – $P_{UMi}^{(1)}$, and the value of $P_{UD}^{(1)}$ later. The estimate $P_{Ub}^{(1)}$ of parameter P_{Ub} can be found analogously (by using formula (15)). It is evident that

$$P_{Ub}^{(1)} > P_{Ub}\,. \qquad (19)$$

If (when there is no control)

$$P_{Ub} < \prod_{i=1}^{n} P_{Ui}\,, \qquad (20)$$

then after its correct application

$$P_{Ub}^{(1)} > \prod_{i=1}^{n} P_{Ui} > P_{Ub}\,. \qquad (21)$$

However both in the first (see formulas (13)-(15)) and in the second (see formulas (16)-(20)) cases the probabilities that the inappropriate HT will be sanctioned for the implementation are considerably less than the product of task accomplishment probabilities of all modules. That in turn determines the possibilities of application of these methods when improving the efficiency of HT.

Conclusions

1. In many cases the reliability of BT is insufficient when using BT technologies.
2. There are several methods for improvement of efficiency of BT technologies. Some of these methods are already sufficiently thoroughly investigated. Still there is a lack of techniques for improvement of efficiency of continuous HT implementation control and methods for its evaluation.
3. HT implementation efficiency depends on the modality of these technologies ant integrality of their control.
4. The differential control of implementation of HT components is more efficient than the integral in considered cases.
5. Application of continuous control of implementation of HT components is more efficient when the task accomplishment probabilities of the modules are relatively not high.
6. When using the methods of majoritarian control, the control efficiency of implementation of HT components is increased. Certainly, these control methods require additional measures, but it is advisable to use them in order to achieve the maximum efficiency of HT.

7. When performing the continuous control of implementation of HT components and when additionally using management of these components and control, even higher efficiency of these technologies (compared to the cases when management is not used) can be achieved.

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In most cases when developing biotronics systems (BTS) it falls to seek maximum efficiency of these systems, despite the required input of material ant time resources. Several methods applicable when improving the efficiency of hazardous BT technologies (HT) were discussed. It was proved, that HT efficiency depends on the modularity of these technologies and their control integrality. Using mathematical expressions it was shown that differential control of implementation of HT components is more efficient than its integral counterpart. It was indicated, that advantage of differential control of HT performance (when compared to integral) is higher in cases when task accomplishment probabilities of modules of these technologies are relatively small. It was proved analytically that when using the majoritarian methods of control of components of these technologies, overall task accomplishment probability increases. It is recommended to use the adaptive management of procedures when performing the majoritarian control of implementation of HT components. Ill. 7, bibl. 7. (in English; summaries in English, Russian and Lithuanian).

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Указано, что во многих случаях при создании систем биотроники (СБТ) приходится стремиться к максимальной эффективности указанных систем, не считаясь с материальными и временными затратами. Приведено несколько способов повышения эффективности опасных технологий (ОТ) БТ. Показано, что эффективность ОТ зависит от их модульности и интегральности контроль их исполнения. Математическими выражениями показано, что дифференциальный контроль исполнения компонентов ОТ обеспечивает большую эффективность, чем интегральная. Из предложенных расчетов следует, что преимущество дифференциального контроля исполнения заданий компонентов ОТ больше в тех случаях, когда вероятности выполнения их заданий, сравнительно, невелики. Из приведенного материала видно, что при использовании мажоритарного контроля исполнения заданий компонентов ОТ повышается эффективность указанной технологии. Рекомендуется при осуществлении постоянного контроля исполнения заданий компонентов ОТ применять адаптивное управление этими компонентами с мажоритарными устройствами. Ил. 7, библ. 7 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Gužauskas, N. Dubauskienė, D. Navikas, A. Valinevičius. Pavojingų biotronikos technologijų efektyvumo užtikrinimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – No. 3(91). – P. 107–112.

Daugeliu atveju, kuriant biotronikos sistemas (BTS), reikia siekti maksimalaus jų efektyvumo, nepaisant materialinių, o dažnai ir laiko sąnaudų. Aptarta keletas būdų, kaip padidinti pavojingų BT technologijų (PT) efektyvumą. Parodyta, kad PT efektyvumas priklauso nuo jų modalumo ir kontrolės integralumo. Matematinėmis išraiškomis parodyta, kad diferencinė PT komponentų vykdymo kontrolė yra efektyvesnė nei integrinė. Diferencinės PT vykdymo kontrolės pranašumas (palyginti su integrine) pasireiškia tais atvejais, kai šios technologijos modulių užduočių įvykdymo tikimybės yra palyginti nedidelės. Analitiškai įrodyta, kad, naudojant mažoritarinės šių technologijų komponentų kontrolės metodus, padidėja užduoties įvykdymo tikimybė. Atliekant mažoritarinę PT komponentų vykdymo kontrolę, rekomenduojama papildomai taikyti adaptyvų procedūrų valdymą. Il. 7, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).