Variation of the entropy analysis method in information flows of IBS in the concept of safe navigation development

AA Vasiutina, VV Popov, AI Kondratyev

Admiral Ushakov Maritime State University, 93, Lenin Ave., Novorossiysk, 353924, Russian Federation

E-mail: 061202@rambler.ru

Abstract. The creation of a configuration by a bridge integrated system in the form of the control machine variation - artificial intelligence, becomes relevant in the concept of E-navigation development with the vector of the vessel’s directional control on the course, both in a small crew and unmanned way. It is possible to consider a large number of mathematical ideas about the basis for creating an intelligent control machine: an artificial neuron and fuzzy sets, Petri nets and Markov chains, Kolmogorov’s differential equations, which are difficult to configure and cumbersome to compute. Multiagent systems seem to be feasible. Integrated bridge systems with embedded supplementary reality assist management personnel in solving navigation issues. Saturation of the navigation control information complex of the bridge system with an increasing number of hardware and instrument units leads to a decrease in information entropy but does not bring to the full automatic control. In ergatic systems, object control is still reduced to declining the uncertainty to a minimum value by means of the operator’s control actions. The methodology for analyzing the entropy capacity of the system and elements of the augmented virtual assessment of the situation in the configuration of multifunctional machine units can be applied in the efficiency criteria development for vessel’s control systems with small crew or unmanned navigation in the concept of E-navigation.

1. Introduction

The creation of a configuration by a bridge integrated system in the form of the control machine variation - artificial intelligence, becomes relevant in the concept of E-navigation development with the vector of the vessel’s directional control on the course, both in a small crew and unmanned way. It is possible to consider a large number of mathematical ideas about the basis for creating an intelligent control machine: an artificial neuron and fuzzy sets, Petri nets and Markov chains, Kolmogorov’s differential equations, which are difficult to configure and cumbersome to compute. Multiagent systems seem to be feasible. However, in any case, the main condition is the flexibility and stability of the system in a complicated changing and operational situation when the vessel moves on its course.

2. Problem statement

The information used by the operator of the marine ergatic system is assessed by the amount of data and transmitted information[1]. A quantitative assessment of information is given through the concept of entropy:
\[ H = \log \bar{N} = -\sum_{i=1}^{N} p_i \log p_i \]  

(1)

Information entropy is the logarithm of the available states number (the base of the logarithm can be various; it determines the unit of entropy measurement).

If we consider events and a set of emerging factors as the information field attractor, then the vessel’s safe control becomes a variability of decisions depending on the changing situation, and the navigation pass is the of the optimized way. A mathematical model of a control system in a simple form can be as a description of control system elements:

In this case, the polynomial is presented as a proper operator:

\[ a_{n,e}p^n + a_{n-1,e}p^{n-1} + \ldots + a_{1,e}p + a_{0,e} = D_e(p) \]  

(2)

Then the input operator of the influence of the information-control signal is:

\[ b_{mk,e}p^m + a_{m-1,k}p^{m-1} + \ldots + a_{1,k}p + b_{0,k,e} = k_{ek}(p) \]  

(3)

Information pulses are presented to the watchkeeper operator by a sequence of mathematical models of occasional phenomena developing in time, while the state is a random variable at the current time \( \xi(t,w) \) [2].

In the space of elementary events \( \Omega, \sigma \) - the algebra of its subsets is \( F \), then for any event of \( A \subset F \) its probability is defined as \( P(A) \), thus, the probability space is given in the form of \( \langle \Omega, F, P \rangle \).

Sequential instantaneous pulses are found through the Laplace transformation in contemporary automatic control systems at Z-transformations:

\[ x^*(s) = \int_0^\infty x^*(t) \cdot e^{-st} dt \]  

(4)

or

\[ x^*(s) = \sum_{n=0}^{\infty} x(nT) \cdot \delta(t-nT) \cdot e^{-st} dt \]  

(5)

Then the formula for inversion of information pulses is a discrete value of the function by its Z-transformation and is determined by the contour integral:

\[ x(nT) = \frac{1}{j \cdot 2\pi T} \cdot \oint_{|z|=1} x(z) \cdot z^{n-1} dz \]  

(6)

In the event of a signal with the next sending moment of single pulses of Z-transformation carrier information, signal is delayed by \( \Delta T \), then the sequence of instantaneous pulses has the form:

\[ x^*(t) = \sum_{n=1}^{\infty} x(nT-\Delta T) \cdot \delta(t-nT) \]  

(7)

The mathematical description of the process can be represented as an augmented continuous Fourier transformation with a discrete frequency:

\[ x^*(t) = \sum_{n=-N/2}^{N/2} s_n \cdot \exp\{j \cdot 2\pi \cdot n\Delta f \cdot t\} \cdot \exp\{j \cdot 2\pi \cdot f_c \} \]  

(8)

where: \( s_n \) is complex symbol of automatic control model; \( n\Delta f \) - discrete frequency (subcarrier); \( f_c \) - carrier frequency.

Total entropy of the control object is:
\[ H_\varepsilon = H_\varepsilon (p) + H_\varepsilon (q) \]  

When the number of states groups is equal to \( N_p \), the entropy of the system operating state is:

\[ H_\varepsilon (p) = \sum_{j=1}^{N_p} \left( \prod_{i_j} p_{i_j} \prod_{k_j} q_{k_j} \right) \log_2 \left( \prod_{i_j} p_{i_j} \prod_{k_j} q_{k_j} \right) \]  

where: \( N_p \) is a total number of operating states, in each \( j \)-th of which the number of exploitable elements is \( l_j \) - and the failed is \( k_j \).

![Figure 1. Schematic diagram of a vessel steering system](image)

3. Materials and methods

Object control is reduced to decreasing the uncertainty to a minimum value determined by the error dispersion of \( D_{xe} \) [3]. Saturation of the navigation and control information complex of the bridge system with an increasing number of hardware and instrument units, including augmented reality systems and all-round visors in the infra- and extra-ranges of visualization of the vessel's navigation safety zone, turns maritime navigation into a sequential series of decision-making or their choice from NCIC knowledge bases. The human role of being creative in navigating and making non-trivial decisions of an active mind is declining. Currently, a watchkepeer assistant of the officer on the bridge often performs only the functions of a controller and observer, and not a full-fledged navigator. A virtual interface with augmented reality and information-entropy stability of the navigator in various extremely complicated situations of the vessel pass on the course is created in the concept of the safe navigation development. Let us represent the basis of the mathematical model of a multidimensional system in the time domain as a formalized record of a vessel in the water area and in space, as a vector-matrix form of a system record of first-order differential equations, or an equation of state [4] in the form of:

\[ \frac{d}{dt} X(t) = AX(t) + BU(t) \]  

where: \( X(t) \) is a dimension state vector of \( n \), including object variables which reflect its state.
All virtual objects of one subspace should be placed in only one location system, that is, \( \Theta \) has a specific location as the vessel in \( \nu \), is defined by the function of \( \pi : \)

\[
\pi : \Theta \rightarrow \nu
\]  

(12)

so that we get

\[
\theta \in \pi(\theta) \notin \nu
\]

(13)
or by modifying the function, we obtain:

\[
\Theta \notin \nu \iff \pi(\theta) \nu
\]

(14)

where \( \theta \in \Theta \), \( \nu \notin \nu \)

Thus, the vessel controlled position in virtual space is implemented as follows:

\[
\forall \theta \notin \Theta \exists \nu \notin \nu
\]

(15)

at

\[
\pi(\theta) = \nu, 1 \leq j \leq n + m + \# \Delta, i \in I
\]

(16)

By transforming, we receive augmented reality:

\[
\forall \chi \in \nu, \pi(\chi_{c \rightarrow}) = h(\chi); \pi(\chi_{c \rightarrow}) = t(\chi)
\]

(17)

4. Results

We investigate a specific model of a vessel in virtual space on the “world ocean” virtual water area introducing the concepts of functions of position and size - \( p, \bar{p}, \pi, \pi, \overline{\pi} \), of a coordinate system - \( \Sigma \), measurements - \( d, d, d \), and a parameter of navigation safety zone - \( k \) [5]. We obtain a certain amount of subspace in three-dimensional space:

\[
V = \bigcup_{\nu} \{\nu\} \subseteq R^3
\]

(18)

where: \( \Sigma = R^3 \) is a function of \( \overline{\pi} \) defines the position of the subspace; \( V \) is a function in three-dimensional coordinate system; \( \overline{p} \) designates the volume of each subspace \( V \) in three-dimensional space.

Then the function

\[
\pi : \Theta \rightarrow \Sigma = (R^3, d) \forall \nu \in I
\]

(19)
indicates the position of each element $\Theta_{i\nu}$ in three-dimensional coordinate system, and the function of $p_{i\nu}$ - the volume in space $\theta_{i\nu}$, metrics $d$ in the coordinate system:

$$\Sigma = \sum_{i\nu} = R^3$$

Then we obtain the vessel model definition in the virtual space in water area [6]:

$$d_{v}(x, y) = d_{v}(x, y) = \left(\sum_{i=1}^{3}(x_i - y_i)^2\right)^{\frac{1}{2}}$$

$$\forall i \in I, \forall x = (x_1, x_2, x_3), y = (y_1, y_2, y_3) \in R^3$$

The navigation safety zone of the vessel in the virtual water area as the propagation of the event is:

$$\rho(s, k) = \{x \in \xi = \pi(s) : d_{v}(s, \pi_{\xi}(x)) \leq k ; k > 0 \in R\}$$

5. Conclusion

The presented methodology for the entropy capacity analysis of the system and elements of the augmented virtual assessment of the situation in the configuration of multifunctional machine units can be applied in the efficiency criteria development for control systems of vessels with small crew or unmanned navigation in the concept of E-navigation [7].

References

[1] Iyudu KA 1966 Optimization of automation devices according to reliability criteria (L.: Energiya).

[2] Dulesov A S, Semenova MYu, Khrustalev VI 2011 Entropy properties of a technical system. Fundamental Research 8631-636

[3] Wilde DJ 1968 Methods for finding an extremum (Moscow: Nauka)

[4] Malkovskaya IA 2004 Communication sign. Discursive Matrices (Moscow: Editorial URSS)

[5] Prigogine I, Stengers I 2003 Order from chaos (Moscow: URSS)

[6] Popov VV 2003 Development and security of the southern ports of Russia. (M.:RosKonsult)

[7] Shkanov V V, Popov V V 2018 A network-centric principle for constructing a flow control structure for unmanned vessels and the creation of a model of an automatic transport process control system by the synthesis of a control Petri net. 6 (139) 252-257