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WYMAGANIA WSTĘPNE DOTYCZĄCE WYKORZYSTANIA FUNKCJI I SKALI OCENY JAKOŚCI ENTROPII W CELU OKREŚLENIA STANU JAKOŚCI SYSTEMÓW TECHNICZNYCH

Streszczenie: Zaproponowano funkcję i skalę oceny stanu jakości systemów technicznych, które spełniają wymogi uniwersalności oraz maksymalnej niezależności od wpływu subiektywności czynnika ludzkiego. Wykazano zgodność proponowanej funkcji z wymaganiami dotyczącymi funkcji oceny jakości. Należy zauważyć, że proponowana skala entropowej oceny jakości ma dynamiczny zakres oceny, który pozwala na automatyczną zmianę granic podpasma w zależności od wymogów regulacyjnych i technicznych dla stanu badanego czujnika. Ponadto skala jest dostosowana do specyficznych wymagań, co pozwala na zwiększenie wiarygodności oceny stanu jakościowego badanego obiektu.

Słowa kluczowe: skala oceny entropii, stan czujnika, dynamiczny zakres oceny, jakościowe modelowanie stanu, infrastruktura czujników, system cyber-fizyczny.

PREREQUISITES OF ENTROPY QUALITY ASSESSMENT FUNCTION AND SCALE USE FOR TECHNICAL SYSTEMS QUALITATIVE CONDITION DEFINITION

Summary: Function and scale of technical systems qualitative condition assessment which meet requirements of universality and maximum independence of a human factor subjectivity influence are offered. The offered function compliance to functions quality assessment requirements is proved. It is noted that the entropy quality assessment offered scale has the dynamic range of estimation that gives the chance of subranges borders automatic change depending on normative and technical requirements to a studied sensor condition. Also the scale adapts under concrete requirements that allows to increase reliability of studied object qualitative condition assessment

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1. Introduction

Qualimetrical assessment of the studied objects quality, that is quantitative definition of quality indicators is, as a rule, carried out on the fuzzy logic theory basis with application of psychophysical scales. The main lack of such approach is the subjective character of results relation of measurement function to the accepted quality scale by the expert. The most known and applied to quality assessment is function and the corresponding scale of desirability of Harrington which was developed for the mass use goods quality assessment purpose.

Analysis of the last researches and publications.
For this time Harrington's function is applied as universal at assessment of separate goods and services quality, assessment of technical systems quality (including the information security systems), economic and social systems. At the same time there is a question concerning correctness of its use as a function and a scale as they were developed by Harrington on the basis of empirical researches of expert conclusions only for mass goods production without research of their application for other objects [1], [2], [3], [4], [5], [6], [7].

Research problem is function and an assessment scale of a technical systems qualitative condition development which satisfy universality and maximum independence requirements from a human factor subjectivity influence.

Statement of the main research material.
Let's define the main requirements to a method and function of technical systems quality assessment:
− universality (possibility of application for assessment of any technical system and its components quality);
− maximum independence of a human factor (expert's subjective decision).
For definition of quality assessment function we will address the researches given in [8], [9], [10] where the principles of uniform (universal) approach to identification of the current information state of cyberphysical (technical) system based on definition of its touch infrastructure (TI) condition, and definition that any information on a research object, the subject will receive on the basis data on a condition of sensors by results of measurement are formulated.

2. Function and scale of entropy assessment of a quality simple indicator

According to [10] we will take the number of own information of its current state received as a result of measurement for information condition of any SI sensor of the technical system (TS):

$$I\left(s_{meas}\right) = -\log p\left(s_{meas}\right), \tag{1}$$

where $(s_{meas} \in S)$ − result of measurement, S - the alphabet of the sensor conditions, $p(s_{meas})$ − probability of acceptance by the state sensor $(S \sim s_{meas})$.

For each operational measurement, depending on a stage technological (technical, program) process there is an expected (aprioristic) condition of the sensor $\left(S \sim s_{exp} \middle| s_{exp} \in S\right)$ come into as a result of analytical calculations or by corresponding process modeling. The aprioristic probability of such state for this measurement corresponds to the maximum value $\left(p\left(s_{exp}\right) \to \max \middle| s_{exp} = M_0\right)$ of the accepted probabilistic distribution where M_0 − mode of distribution. The number of the expected own information of a sensor aprioristic condition:

$$I\left(s_{exp}\right) = -\log p\left(s_{exp}\right). \tag{2}$$

The relative value of own information of a sensor condition, according to (1, 2) can be presented by expression:

$$I_S^{\Delta} = \frac{I(s_{meas})}{I\left(s_{exp}\right)} = \frac{\log p(s_{meas})}{\log p\left(s_{exp}\right)}. \tag{3}$$

According to ISO 25021 [12] the quality indicator element (QIE) is the indicator defined in terms of property and a method of measurement for this property quantitative determination, and a quality indicator − the indicator received as measurement function not less than two indicators. Having taken for one QIE measurement result (the number of own information of the sensor current state) $I(s_{meas})$, and for the second − the number of own information of the sensor expected condition $I\left(s_{exp}\right)$, according to (3) we will define the simple indicator of quality (SIQ) as the QIE function that equals to the inverse value of sensor condition own information relative value :

$$SQM = \frac{1}{I_S^{\Delta}} = \frac{I\left(s_{exp}\right)}{I(s_{meas})} = \frac{\log p\left(s_{exp}\right)}{\log p(s_{meas})}. \tag{4}$$

In general, quality assessment function has to meet the following requirements: area of values $0 \le f_{quality} \le 1$, continuity, monotony, smoothness [3]. Let's consider expression (4) concerning compliance to the specified requirements.

As the expected value of the message s_{exp} has the maximum probability, its own information will be minimum $I\left(s_{exp}\right) \to \min \left| p\left(s_{exp}\right) \to \max\right.$, that is $I\left(s_{exp}\right) \le I(s_{meas})$, and equality will be only in case the expected value equals to measured $\left(s_{exp} = s_{meas}\right)$. From here: $\frac{1}{I_s^{\Delta}} = \frac{I\left(s_{exp}\right)}{I(s_{meas})} \le 1$.

Let's consider a case when distribution of a random variable probability $(s \in S)$ belongs to absolutely continuous distributions. In expression (4) let's accept that $p(s_{exp}) \neq 1$, and function $p(s_{meas})$ is differentiated on all set of definition $S = \{s_{min} : s_{max}\}$, increases on an interval $[s_{min} : s_{exp}]$, falls down on an interval $[s_{exp} : s_{max}]$ what follows from that $p'(s_{meas}) \geq 0$ on $[s_{min} : s_{exp}]$ and $p'(s_{meas}) \leq 0$ on $[s_{exp} : s_{max}]$. If for some s_{meas}, $p(s_{meas}) = 0$, then we have $SQM(s_{meas}) = \lim\limits_{p(S_{meas}) \to 0} \dfrac{\ln(p(s_{exp}))}{\ln(p(s_{meas}))} = \left[\dfrac{const}{\infty}\right] = 0$, supplementing value of function with extreme value which provides the continuity of function in this point. In other points $s_{meas} \in S$ function is continuous as the relation continuous which denominator does not equal to zero (the denominator and numerator are continuous as composition of continuous). In all points function is differentiated as the relation differentiated which denominator does not equal to zero $(\ln(p(s_{meas})) \neq 0)$ (the numerator and a denominator are differentiated as composition of differentiated), and a function derivative $SQM'(s_{meas}) = \dfrac{-\ln(p(s_{exp}))}{\ln^2(p(s_{meas}))\, p(s_{meas})} p'(s_{meas})$ what follows from that the value SQM' is defined by value p'. Function of probability, and respectively function SQM can accept value zero only in some suburb of points s_{min} and s_{max}, in all other points SQM differentiated, according to its monotony is defined by monotony of function of probability. Considering that $SQM \geq 0$, finally we have that SQM increases on $[s_{min} : s_{exp}]$ and falls down on $[s_{exp} : s_{max}]$.

Next, we will consider a case when distribution of probability $p(s)$ belongs to discrete distributions of a random variable $s \in S = \{s_1, ...s_M, .., s_m\}$ where $s_M = M_0$ - mode of distribution. Let's consider that $\begin{cases} p(s_j) \leq p(s_{j+1}) \mid \forall j < M \\ p(s_{j-1}) \geq p(s_j) \mid \forall j > M \end{cases}$.

Applying Ermit's interpolation we will set on a $[s_1 : s_m]$ degree $2m-1$ polynom $g(s)$ so that $g'(s_j) \geq 0 \mid \forall j < M$, $g'(s_j) \leq 0 \mid \forall j > M$, $g'(s_j) = 0 \mid j = M$. Then function $g(s)$ in vicinities of discrete distribution points $p(s)$ will behave as continuous and to it it is possible to apply the analysis to continuous distributions given above.

Thus, the offered function of quality assessment (4) meets all demands made above.

The SIQ quantitative value received according to does not carry information on a qualitative condition of an object (sensor). Process of quality assessment consists in

assessment of the received value belonging to some estimation scale. There is quite big set of the offered scales, however all of them belong to psychophysical which main shortcoming is the subjectivity of the "value → scale" display [2], [5].
According to the requirements to a method and function of quality assessment stated above, the scale based on normative and technical (design, design) requirements concerning the estimated object (sensor) is offered. The principles of technical regulation, definition of technical objects conditions in standards and requirements to scales of quality [5], [13], [14], [15], [16] are taken as a basis of a scale creation.
The scale of quality entropy assessment L^{Δ} (fig. 1), according to area of a simple indicator quality entropy assessment function values SQM, has the range $0 \le L^{\Delta} \le 1$ ($SQM = 1$ corresponds maximum, and $SQM = 0$ - to the minimum value of quality), which breaks into three subranges:
1. Good state − a condition of an object at which it corresponds to all normative and technical (design) requirements.
2. Up state − a condition of an object at which from it is capable to perform the necessary function (a possibility of operation), but stable work and the necessary productivity is not guaranteed.
3. Down state − a condition of an object at which it is not capable to perform the necessary function.
Belonging to a scale subranges is defined by the following expressions:
- Good state, if $SQM\left(s_{exp}, s_{meas}\right) \in \left[SQM\left(s_{exp}, x\right)\right)$, where $\left(s_{exp} - b \le x \le s_{exp} + a\right)$, $\left(a, b\right)$ − an admissible maximum and minimum deviation from the expected value, respectively.
- Up state, if $SQM\left(s_{exp}, s_{meas}\right) \in \left[SQM\left(s_{exp}, y\right)\right)$,
where $\begin{cases} s_{exp} + a < y \le s_{exp} + a + c \\ s_{exp} - b - d \le y < s_{exp} - b \end{cases}$, $\left(c, d\right)$, − the maximum and minimum deviation from admissible values $\left(a, b\right)$, respectively.
- Down state $SQM\left(s_{exp}, s_{meas}\right) \notin \left\{\left[SQM\left(s_{exp}, x\right)\right] \cup \left[SQM\left(s_{exp}, y\right)\right]\right\}$ − in other cases.

3. Function and scale of entropy assessment of a complex indicator of quality

The Complex Indicator of Quality (CIQ) according to [12] will unite several SIQ, or the CIQ of the lowest levels:
$CQM_x = f\left(\left\{SQM, CQM\right\} \middle| \forall SQM \in CQM_x, \forall CQM \in CQM_x\right)$ where x − the index of any CIQ.
Considering property of own information additivity [11], calculations of sensors generalized set CIQ quantitative value, on their SIQ independence condition [8], [14],

and (4) is carried out by expression:

$$CQM = \frac{1}{I_Z^\Delta} = \frac{\sum_z -\log\left(p\left(Z \sim z_{exp}\right)\middle|\forall z_{exp} \in Z\right)}{\sum_z -\log\left(p\left(Z \sim z_{meas}\right)\middle|\forall z_{meas} \in Z\right)}, \quad (5)$$

where Z − any sets (components) of technical system touch infrastructure models [9], z_{exp} − the expected (aprioristic) of the corresponding component condition value, z_{meas} − the current (measured) value of a condition of the corresponding component. The scale of entropy quality assessment L^Δ for complex indicators coincides with a scale for simple indicators and has the same subranges. However, reference calculated on (5) CQM to subranges has the differences caused by an essence of subranges and definition of the CPC as the indicator uniting several SIQ or CIQ of the lowest levels. Therefore, it can be treated as the integrated object which quality is defined by set of qualitative conditions (quality of realization of functions) of several objects. Belonging of a condition of such object to subranges of a scale is determined by the minimum (worst) value of quality of the making objects as non-performance or partial performance of one function means non-performance (partial performance) of the joint function.
Belonging to a scale subranges is defined by the following expressions:

− Down state if at least one of SIQ that make this CIQ has a down state
$$\left[\exists SQM \in \left[SQM < SQM\left(s_{exp} + y\right)\right] \middle| \forall SQM \in CQM\right].$$
− Up state if at least one of SIQ making this CIQ has up state and any of them has no down state
$$\left[\left(\exists SQM \in \left[SQM\left(s_{exp} + y\right)\right]\right) \wedge \left(\forall SQM \notin \left[SQM < SQM\left(s_{exp} + y\right)\right]\right) \middle| \forall SQM \in CQM\right)$$

− Good state if any of SIQ making this CIQ has no operating or down state
$$\left[\left(\forall SQM \notin \left[SQM\left(s_{exp} + y\right)\right]\right) \wedge \left(\forall SQM \notin \left[SQM < SQM\left(s_{exp} + y\right)\right]\right) \middle| \forall SQM \in CQM\right)$$

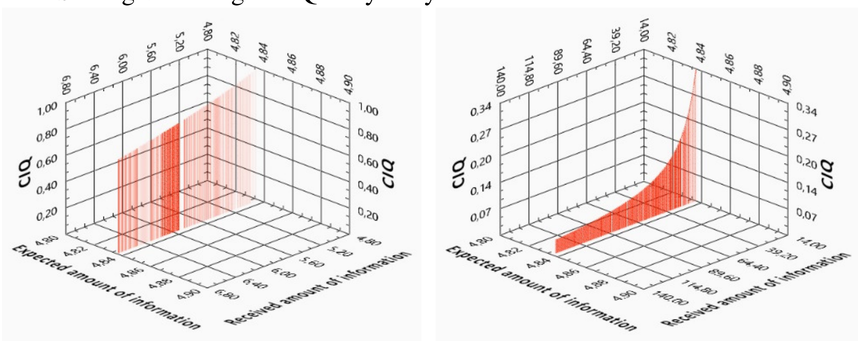
It should be noted that the quantitative value of complex indicators of quality CQM calculated according to (5) in this definition does not influence definition of their accessories to scale L^Δ subrange, and has only informative character and it is intended for a further research of an object (system) qualitative condition.
Are given results of modeling of a qualitative condition of the system consisting of two sensors (a complex indicator of quality) which below was carried out according to (5).

1. The sensor with the alphabet $S^1 = \left(\overline{0,30}\right)$, distribution $P(\lambda = 5)$ and normative and technical requirements to assessment of a qualitative condition of the sensor: good state: (5 ± 2) messages, up state: $\begin{cases} 2 \le \text{ messages } < 3 \\ 7 < \text{ messages } \le 8 \end{cases}$ down state: $\begin{cases} \text{messages } < 2 \\ \text{messages } > 8 \end{cases}$.

2. The sensor with the alphabet $S^2 = \left(\overline{-30,30}\right)$, distribution $N(3,2)$ and normative and technical requirements: good state: $0 \le$ alphabet S value ≤ 5 up state: $\begin{cases} -5 \le \text{ alphabet } S \text{ value } < 0 \\ 5 < \text{ alphabet } S \text{ value } \le 10 \end{cases}$ down state: $\begin{cases} \text{alphabet } S \text{ value } < -5 \\ \text{alphabet } S \text{ value} > 10 \end{cases}$.

The result of modeling at good state of the sensor S^1 and good state of the sensor S^2 is given in fig. 1a. Quality of system - serviceable

The result of modeling at good state of the sensor S^1 and a disabled condition of the sensor S^2 is given in fig. 1b. Quality of system - disabled.



a b

Figure 1 - Result of system qualitative modeling

a - at good state of the sensor S^1 and good state of the sensor S^2

b - at good state of the sensor S^1 and a disabled condition of the sensor S^2

4. Conclusion

In paper function and a scale of technical system current state entropy quality assessment which meets the requirements of universality and maximum independence of a human factor are offered. Compliance is ensured by the evaluation of the information loss by sensors of the hardware, software and functional infrastructures of the system, with according to the planned values. Compliance to the offered function to requirements to functions of quality assessment is proved. Unlike the existing psychophysical scales the offered scale of entropy quality assessment has the dynamic range of estimation that means automatic change of its subranges borders depending on normative and technical requirements to a studied sensor condition, that is the scale adapts under concrete requirements that allows to estimate a qualitative condition of system more authentically. Results of system qualitative condition change modeling at a working and able-bodied order of sensors are given.

Possible practical application of the offered function and scale is used in the systems of monitoring and diagnostics, for definition of the current qualitative state of the studied technical system.

Further researches are planned in the field of qualitative condition definition modeling of information security and critical infrastructure systems.

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