Applied problems of information systems operation

UDC 519.237.5 **doi:** https://doi.org/10.20998/2522-9052.2023.1.11

Ihor Hryhorenko, Svitlana Hryhorenko, Oleksandr Zhuk

National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine

THE USE OF CORRELATION ANALYSIS IN ASSESSING THE UNCERTAINTY OF THE INFLUENCE OF EXTERNAL FACTORS ON THE RESULT OF THERMAL CONTROL OF BIOLOGICAL OBJECTS

Abstract. Research task. The paper considers the solution of the scientific and practical problem of determining the influence of external factors on the result of non-contact thermal control of biological objects. **Object of study.** A human was chosen as a biological object. **Research progress.** Establishing the correlation dependence was carried out in the two most opposite seasons in terms of climate parameters – winter and summer. One person was taken for the study, whose temperature was measured using a FLIR Vue Pro R 640 thermal imager mounted on a Cheerson CX-20 quadcopter at one-hour intervals throughout the day. The data were obtained in the summer period on August 10, 2022. In the winter period, measurements were carried out on January 20, 2022. **Research results.** Conclusions were made about the absence of a linear correlation between humidity, air temperature and body temperature of BO in the summer period. On the contrary, a high correlation was established between all the indicated parameters in the winter period. Conclusions were made about the need to develop a mathematical model of the factor influence on the thermal control result of the BO in order to obtain analytical ratios for evaluating the quantitative information on each of the temperature control indicators under the factor influence on the conversion function of these indicators. It is noted that such a model will make it possible to rank the indicators of temperature control according to the decrease in their sensitivity to changes in the levels of the temperature control parameter. **Usage suggestions.** It is proposed to calculate the correcting coefficients to determine the exact value of the body temperature, because it was experimentally established that the values of the body temperature in the winter period differ from the actual values precisely due to the influence of the temperature of the external environment.

Keywords: biological object; correlation; measurement; control; uncertainty.

Introduction

It is universally known that the body temperature of a biological object (BO) is one of the indicators of the body's health. Heat in the body of the BO is generated as a result of muscle activity, assimilation of food and all life processes that ensure metabolism. BO dissipates heat by radiation, conduction, and evaporation of water from the respiratory tract and skin surface. In turn, the temperature is maintained at the appropriate level thanks to the thermoregulation centers of the cerebral cortex, the central thermocenters of the hypothalamus, and the peripheral thermocenters of the skin and blood vessels [1]. In the summer period, when the air temperature is high enough, the blood vessels expand, sweat increases, which regulates heat transfer, and heat production decreases. This property of BO protects the body from overheating. On the contrary, in the winter period, at low air temperatures, the body's immune system acts in the opposite way, namely: the thermal conductivity of the skin decreases, blood vessels narrow and the contractile activity of skeletal muscles increases – chills appear. As a result of chills, heat is released and the body thus tries to maintain body temperature [1].

Analysis of the last achievements and publications. In works [2 – 6] it is noted that it is necessary to control the temperature of BO (especially when they accumulate) for the timely identification of patients and their exclusion from society in order to counteract the spread of the viral disease. Temperature control is proposed to be carried out by a non-contact method, thanks to the use of a thermal imager installed on a quadcopter.

Formulation of the article purpose. At this time, the issue of determining the impact of seasonal changes in temperature and air humidity on the result of determining the temperature of the BO remains unresolved. In order to establish a relationship between the specified factors and the control parameter and to determine the degree of significance of the correlation coefficient, calculated from a limited number of observations, it is suggested to use correlation analysis. Correlation analysis makes it possible to measure the degree of influence of factor characteristics on the results, to establish a single measure of the closeness of the relationship and the role of the studied factor (factors) in the overall change of the resulting characteristic.

The correlation method allows you to obtain quantitative characteristics of the degree of connection between two or more features, gives a broader idea of the connection between them. The relationships between the factors are quite diverse. At the same time, some signs act as factors acting on others, causing their change, while others act as the action of these factors. It is also necessary to determine the significance of the correlation coefficient in order to take it into account when calculating the expanded uncertainty for correlated data.

Statement of the main material

The concept of linear correlation between two quantities is well known, but in our case we are talking about the case of correlation of three quantities: air temperature, air humidity and their influence on the temperature of the BO. It should be noted that if a linear correlation between the specified parameters is not established, then this does not exclude the case of nonlinear dependence between them. Let's start with testing the hypothesis about the existence of a linear correlation between the factors and the control parameter.

The correlation between x and y values belonging to two processes is called linear if both regression functions are linear. In this case, the regression lines are transformed into straight regressions, the angular coefficients of which are expressed through the correlation coefficient. This coefficient acts as a measure of linear dependence between values [7–11]. The case of correlation between two quantities can be transferred to the case of a larger number of quantities. Let's consider the case of the interaction of three quantities, namely, establish the relationship between the body temperature of the body BO (*t*), air humidity (*h*) and air temperature (*a*).

The regression density (*t*) on (*h*, *a*) has the form:

$$t-\bar{t}=b_{t|h}\left(h-\bar{h}\right)+b_{t|a}\left(a-\bar{a}\right), \quad (1)$$

where $b_{t|h}$, $b_{t|a}$ – regression coefficients determined by correlation coefficients between pairs of values (*h*) and (*a*), (*h*) and (*t*), (*a*) and (*t*) as follows:

$$b_{t|h}=\frac{r_{ht}-r_{ha}\cdot r_{at}}{1-r_{ha}^2}\cdot\frac{s_t}{s_h},$$

$$b_{t|a}=\frac{r_{at}-r_{ha}\cdot r_{ht}}{1-r_{ha}^2}\cdot\frac{s_t}{s_a}. \quad (2)$$

Correlation coefficients are determined by the following formulas:

$$r_{ha}=\frac{\sum\left(h_i-\bar{h}\right)\cdot\left(a_i-\bar{a}\right)}{(N-1)s_h s_a},$$

$$r_{at}=\frac{\sum\left(a_i-\bar{a}\right)\cdot\left(t_i-\bar{t}\right)}{(N-1)s_a s_t},$$

$$r_{ht}=\frac{\sum\left(h_i-\bar{h}\right)\cdot\left(t_i-\bar{t}\right)}{(N-1)s_h s_t}, \quad \left(\sum=\sum_{i=1}^{N}\right),$$

where *N* – the total number of results of the experiment, that is, the total number of points $\left(h_i, a_i, t_i\right)$, and s_h, s_a, s_t – empirical standards:

$$s_h^2=\frac{\sum\left(h_i-\bar{h}\right)^2}{(N-1)},$$

$$s_a^2=\frac{\sum\left(a_i-\bar{a}\right)^2}{(N-1)},$$

$$s_t^2=\frac{\sum\left(t_i-\bar{t}\right)}{(N-1)}.$$

The measure of dependence between the value (*t*) and the values (*h*) and (*a*) is the combined correlation coefficient:

$$R=\sqrt{\frac{r_{ht}^2+r_{at}^2-r_{ha}\cdot r_{ht}\cdot r_{at}}{1-r_{ha}^2}}=$$

$$=\sqrt{\begin{array}{l}1-\dfrac{1}{(N-1)\cdot s_t^2}\times \\ \times\sum_{i=1}^{N}\left[t_i-\bar{t}-b_{t|h}\left(h_i-\bar{h}\right)-b_{t|a}\left(a_i-\bar{a}\right)\right]^2\end{array}}. \quad (3)$$

The combined correlation coefficient always lies in the range from 0 to 1.

If the value of (*t*) does not depend on (*h*) and (*a*), then the theoretical value of (*R*) will be equal to 0. If it is determined that the theoretical value of (*R*) is equal to 0 (or very small), then between the value of (*t*) and the values (*h*) and (*a*) do not have a linear correlation dependence, but may be nonlinear.

The combined correlation coefficient is equal to 1 if and only if all experimental points lie in the regression plane.

The theoretical value of (*R*) will be equal to 1 only in the case of a linear functional regression of (*t*) and the values of (*h*) and (*a*).

To study the influence of only one of the factors, for example (*h*), on the value of (*t*), that is, to study the correlation between (*h*) and (*t*) after eliminating the measurements caused by the value of (*a*), enter the private correlation coefficient of the values of (*h*) and (*t*) in relation to the value of (*a*):

$$r_{ht|a}=\frac{r_{ht}-r_{ha}\cdot r_{at}}{\sqrt{1-r_{ha}^2}\cdot\sqrt{1-r_{at}^2}},$$

$$r_{at|h}=\frac{r_{at}-r_{ha}\cdot r_{ht}}{\sqrt{1-r_{ha}^2}\cdot\sqrt{1-r_{ht}^2}},$$

$$r_{ha|t}=\frac{r_{ha}-r_{ht}\cdot r_{ta}}{\sqrt{1-r_{ht}^2}\cdot\sqrt{1-r_{ta}^2}}.$$

We will perform a calculation in order to detect the presence of a correlation dependence in the interaction of three quantities, namely, we will establish a relationship between human body temperature (*t*), air humidity (*h*) and air temperature (*a*).

One person was taken for the study, whose temperature was measured using a FLIR Vue Pro R 640 thermal imager mounted on a Cheerson CX-20 quadcopter at one-hour intervals throughout the day. The data were obtained in the summer period of 10.08.22. In the winter period, measurements were carried out on 20.01.22.

The FLIR Vue Pro R 640 thermal imager is available in several versions. It is a radiometric thermal imager with an image format of 640 x 512 and a focal length of 19 mm. It can capture video and record it in MJPEG and H.264 format to a microSD memory card. 14-bit photos are also entered there.

The frame rate of the recorded video image is 30 Hz. MAVLink, an information exchange protocol between a ground station and an aircraft [12], is used for the removed parameter settings.

The functional set of the Cheerson CX-20 quadcopter [13] is represented by position and altitude hold modes, an analogue of the Headless mode and the RTH function.

The Autopilot feature causes the CX-20 to automatically return to the operator and land. Take Off mode implies fully manual control. The results of measurements obtained with the help of the specified equipment are summarized in the Table 1.

To detect the presence of correlation between the specified parameters, we will calculate the correlation coefficients and the combined correlation coefficient. Calculations were made using the Microsoft Excel computer program.

The results of the calculations are summarized in the Table 2.

Table 1 – **The results of measuring a person’s temperature in the summer and winter periods**

Time, hours	**Summer. 10.08.22**			**Winter. 20.01.22**		
	Air temperature, ^{0}C	**Air humidity, RH %**	**Human body temperature, ^{0}C**	**Air temperature, ^{0}C**	**Air humidity, RH %**	**Human body temperature, ^{0}C**
00-00	21	81	36,4	-17	93	32,1
01-00	21	83	39,4	-17	93	32,3
02-00	20	86	36,4	-17	93	32,4
03-00	20	89	36,4	-17	92	32,8
04-00	19	90	36,5	-17	91	32,5
05-00	19	90	36,5	-16	90	33,5
06-00	20	91	36,6	-16	89	33,6
07-00	21	82	36,6	-16	89	33,8
08-00	22	73	39,7	-16	89	32,2
09-00	24	64	36,7	-14	89	34,1
10-00	26	53	36,7	-12	89	34,3
11-00	28	46	36,7	-11	89	34,4
12-00	30	42	36,8	-10	88	34,6
13-00	30	38	36,8	-8	87	34,8
14-00	31	35	36,8	-7	86	35,2
15-00	32	33	36,8	-7	86	35,2
16-00	31	34	36,8	-7	85	35,4
17-00	31	35	36,8	-6	84	35,3
18-00	30	36	36,8	-6	84	35,5
19-00	28	44	36,7	-6	85	35,5
20-00	26	52	36,6	-6	86	35,6
21-00	25	63	36,6	-6	86	35,5
22-00	25	69	36,6	-5	85	35,7
23-00	24	76	36,5	-4	84	35,7
24-00	24	80	36,5	-4	84	35,7

Table 2 – **Results of calculations of the main parameters of correlation dependences for the summer and winter periods**

Summer. 10.08.22			**Winter. 20.01.22**		
$s_h = 4,459$	$s_a = 21,652$	$s_t = 0,834$	$s_h = 4,926$	$s_a = 2,964$	$s_t = 1,282$
$s_h^2 = 19,88$	$s_a^2 = 468,81$	$s_t^2 = 0,695$	$s_h^2 = 24,26$	$s_a^2 = 8,783$	$s_t^2 = 1,644$
$r_{ha} = -0,986$	$r_{at} = -0,105$	$r_{ht} = 0,078$	$r_{ha} = -0,932$	$r_{at} = 0,954$	$r_{ht} = -0,932$
	$R = 0,184$			$R = 0,961$	

We will check the significance of the correlation coefficient calculated on a limited number of observations. To check the significance of the correlation coefficient for its further accounting (or ignoring) allows the application of the Student's criterion

$$\frac{|R|}{\sqrt{1-R^2}}\sqrt{n-2} \geq t_p(n-2), \quad (4)$$

where $t_p(n\text{-}2)$ – Student's coefficient for the number of degrees of freedom $(n\text{-}2)$.

When inequality (4) is fulfilled, the correlation coefficient is significant and must be taken into account when calculating the expanded uncertainty for correlated data, which is calculated by the formula:

$$U(y) = k \cdot u_c(y), \quad (5)$$

where k – coverage ratio; $u_c(y)$ – total standard uncertainty.

Since the total standard uncertainty $u_c(y)$ has a contribution of type *A* uncertainty, the coverage factor (*k*) should be defined as [14]:

$$k = t_{0,95}(\nu_{eff}), \quad (6)$$

where ν_{eff} – effective number of degrees of freedom.

Let's evaluate the significance of the combined correlation coefficient between the value of (*t*) and the values of (*h*) and (*a*) obtained in the winter period (20.01.22).

$$\frac{|0,961|}{\sqrt{1-0,961^2}}\sqrt{25\text{-}2} > t_{0,95}(23);$$

$$16,7 > 2,069 .$$

Thus, the aggregated correlation coefficient between the value of (*t*) and the values of (*h*) and (*a*) is significant and should be taken into account when calculating the expanded uncertainty for correlated data.

Summaries

Based on the calculations, the following conclusions can be drawn: in the summer period, there is no linear correlation between humidity, air temperature, and body temperature. Only a high correlation between humidity and air temperature was established. In winter, the situation changes: a high correlation is established between all the specified parameters, which makes it necessary to take it into account when calculating the uncertainty of measurements.

The presence of a correlation relationship requires the development of a mathematical model of the factorial influence on the result of the thermal control of the biological object in order to obtain analytical ratios for evaluating the amount of information on each of the indicators of temperature control with the factorial influence on the conversion function of these indicators.

The model will make it possible to rank the indicators of temperature control according to the decrease in their sensitivity to changes in the levels of the temperature control parameter.

To determine the exact value of the body temperature biological object, it is necessary to determine the correction coefficients, because the obtained values of the body temperature in the winter period differ from the actual values due to the influence of the temperature of the external environment.

REFERENCES

1. Balabina, Zhanna (2022), "Important and interesting information about human body temperature", *Support me*, available at: http://supportme.org.ua/health-and-beauty-care/pro-temperaturu-tila (accessed 03.08.2022), (in Ukrainian).
2. Holovnov, M. & Skoropad, P. (2012), "Prospects for the use of radiation thermometers in medicine", *Vymiryuvalna tekhnika ta metrolohiya*, No. 73, available at: https://science.lpnu.ua/sites/default/files/journal-paper/2018/aug/14021/14-holovnov-63-67.pdf (in Ukrainian).
3. Shlykov, V.V. & Volyanyk, O.M. (2018), "Microprocessor temperature control system", I*nternauka*. International Scientific Journal, available at: https://www.inter-nauka.com/uploads/public/15308083338340.pdf (accessed 25.08.2022 p.) (in Ukrainian).
4. Hryhorenko, S.M., Hryhorenko, I.V. & Zhuk, O.V. (2020), "Analysis of thermal control problems of biological objects", *XIV Mizhnarodna naukovo-praktychna konferentsiya mahistriv ta aspirantiv «Teoretychni ta praktychni doslidzhennya molodykh vchenykh»*, Kharkiv:, pp. 135-136. (in Ukrainian).

5. Hryhorenko, I.V., Hryhorenko, S.M. & Zhuk, O.V. (2021), "Application of microcontroller systems for remote thermal control of biological objects", *XXIX Mizhnar. nauk. – prakt. konf.: Informatsiyni tekhnolohiyi: nauka, tekhnika, tekhnolohiya, osvita, zdorovya*, tom 2,: NTU «KHPI», Kharkiv 2021, p. 299 (in Ukrainian).
6. Zhuk, O.V., Hryhorenko, S.M. & Hryhorenko, I.V. (2021), "Planning of an experiment to determine the temperature of biological objects", *XV Mizhnarodna naukovo-praktychna konferentsiya mahistriv ta aspirantiv «Teoretychni ta praktychni doslidzhennya molodykh vchenykh»*, NTU «KHPI», Kharkiv, p. 70 (in Ukrainian).
7. Karapetyan, N., Benson, K., McKinney, C., Taslakian, P. and Rekleitis,I. (2017), "Efficient Multi-Robot Coverage of Known Environment", *RJS International Conference on Intelligent Robots and Systems*, Vancouver, BC, Canada: IEEE, 24-28 September 2017, pp. 1–7, doi: https://doi.org/10.1109/IROS.2017.8206000
8. Alexandrov, D. & Kochetov, Y. (1999), "Behavior of Ant Colony Algorithm for the Set Covering Problem", *Operations Research Proceedings*, pp. 255–260, doi: https://doi.org/10.1007/978-3-642-58300-1_38
9. Xu, A., Viriyasuthee, C. & Rekleitis, I. (2014), "Efficient Complete Coverage of a known arbitrary environment with applications to aerial operations", Autonomous Robots, 36, pp. 365–381, doi: https://doi.org/10.1007/s10514-013-9364-x
10. Hryhorenko, I., Hryhorenko, S., & Zhuk, O. (2022). "Use of dispersion analysis in building a model of factor influence on the result of remote thermal control of biological objects", *Advanced Information Systems*, Vol. 6, Iss. 3, pp. 23–27, doi: https://doi.org/10.20998/2522-9052.2022.3.03
11. Nazarenko L.A. (2018), *Planning and processing of experiment results*, Kharkiv nats. unt misk. hosp-va im. O.M. Beketova, Kharkiv, 163 p., available at: https://sds.kname.edu.ua/images/doc/nazarenko/ПіОРЕ_КЛ_2018-1-90.pdf (in Ukrainian).
12. (2022), *Teplovizor FLIR Vue Pro R 640*, available at: https://vistrel.kiev.ua/teplovizory (accessed 14.08.2022).
13. (2022), Kvadrokopter Cheerson CX-20, available at: https://kopter.com.ua/detskie-igrushki/radioupravljaemie-igrushki/quadrocopters / (accessed 14.08.2022).
14. Zakharov, I., Neyezhmakov, P., Botsiura, O. (2021), "Expanded Uncertainty Evaluation Taking into Account the Correlation Between Estimates of Input Quantities", *Ukrainian Metrological Journal*, No. 1, pp. 4-8, doi: https://doi.org/10.24027/2306-7039.1.2021.228134

Received (Надійшла) 05.01.2023
Accepted for publication (Прийнята до друку) 22.02.2023

ВІДОМОСТІ ПРО АВТОРА / ABOUT THE AUTHOR

Григоренко Ігор Володимирович – кандидат технічних наук, професор кафедри інформаційно-вимірювальних технологій і систем, Національний технічний університет «Харківський політехнічний інститут», Харків, Україна;
Ihor Hryhorenko – Candidate of Technical Sciences, Professor of the Department of Information and Measuring Technologies and Systems, National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine;
e-mail: grigmaestro@gmail.com; ORCID ID: https:// orcid.org/0000-0002-4905-3053.

Григоренко Світлана Миколаївна – кандидат технічних наук, доцент кафедри комп'ютерних та радіоелектронних систем контролю і діагностики, Національний технічний університет «Харківський політехнічний інститут», Україна;
Svitlana Hryhorenko – Candidate of Technical Sciences, Associate Professor of the Department of Computer and Radio-Electronic Control Systems and Diagnostics, National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine;
e-mail: sngloba@gmail.com; ORCID ID: http://orcid.org/0000-0002-5375-9534.

Жук Олександр Васильович – аспірант кафедри комп'ютерних та радіоелектронних систем контролю та діагностики Національного технічного університету «Харківський політехнічний інститут», Харків, Україна;
Oleksandr Zhuk– postgraduate of the Department of computer and radio-electronic control systems and diagnostics National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine.
e-mail: seozavr@gmail.com; ORCID ID: http://orcid.org/0000- 0003-1496-2836.

Використання кореляційного аналізу при оцінюванні невизначеності впливу зовнішніх факторів результат теплового контролю біологічних об'єктів

І. В. Григоренко, С. М. Григоренко, О. В. Жук

Анотація. Завдання дослідження. У роботі розглянуто вирішення науково-практичної задачі визначення впливу зовнішніх факторів на результат безконтактного теплового контролю біологічних об'єктів (БО). **Об'єкт дослідження.** У якості біологічного об'єкту було обрано людину. **Хід дослідження.** Встановлення кореляційної залежності проводились у два найбільш протилежні за параметрами клімату сезони – зима і літо. Для проведення дослідження було взято одна людина, температура якої вимілювалась за допомогою тепловізора FLIR Vue Pro R 640, що встановлений на квадрокоптері Cheerson CX-20, з інтервалом у оду годину впродовж доби. Дані отримані у літній період 10.08.2022. У зимовий період вимірювання проводились 20.01.2022. **Результати дослідження.** Зроблені висновки про відсутність лінійної кореляція між вологістю, температурою повітря та температурою тіла БО у літній період. І навпаки встановлена висока кореляція між всіма вказаними параметрами у зимовий період. Зроблені висновки про необхідність розроблення математичної моделі факторного впливу на результат теплового контролю БО з метою отримати аналітичні співвідношення для оцінювання кількісті інформації по кожному з показників контролю температури при факторному впливі на функцію перетворення цих показників. Зазначено, що така модель дасть змогу ранжувати показники контролю температури за зменшенням їх чутливості до зміни рівнів параметра температурного контролю. **Пропозиції щодо використання.** Запропоновано для визначення точного значення температури БО проводити розрахунки поправочних коефіцієнтів, бо експериментально встановлено, що значення температури тіла у зимовий період відрізняються від дійсних саме завдяки впливу температури зовнішнього середовища.

Ключові слова: біологічний об'єкт; кореляція; вимірювання; контроль; невизначеність.