SCIENTIFIC BASIS OF INNOVATION

NOVAK, D. S.[1] (https://orcid.org/0000-0002-1796-8857),
MOSHENSKYI, A. O.[2] (https://orcid.org/0000-0002-4584-4958),
BEREZNENKO, S. M.[1] (https://orcid.org/0000-0002-1042-6369),
SERHIIENKO, L. H.[3] (https://orcid.org/0000-0002-1002-2348),
and GUIDA, O. G.[4] (https://orcid.org/0000-0002-2019-2615)

[1] Kyiv National University of Technologies and Design,
2, Nemyrovycha-Danchenka St., Kyiv, 01011, Ukraine,
+380 44 280 5545, knutd@knutd.edu.ua
[2] National University of Food Technologies,
68, Volodymyrska St., Kyiv, 01601, Ukraine,
+380 44 289 5472, info@nuft.edu.ua
[3] State Research Institute of the Ministry of Internal Affairs of Ukraine,
4A, Yevgen Gutsalo Lane, Kyiv, 03680, Ukraine,
+380 44 374 3406, dndekc@mvs.gov.ua
[4] V. I. Vernadsky Taurida National University,
33, John McCain St., Kyiv, 01042, Ukraine,
+380 44 529 0516, crimea.tnu@gmail.com

FUNCTIONAL SYSTEM FOR TEMPERATURE AND RELATIVE AIR HUMIDITY SOFTWARE MONITORING IN INTERLAYER CLOTHING SPACE

Introduction. The study of the parameters of the clothing space is extremely important in the development of seasonal clothing for the military, police, athletes, etc.

Problem Statement. The use of "smart" textiles capable of responding to changes in the environment, adapting to it by integrating functional capabilities into the textile structure, deserves attention.

Person's feeling and emotional response are accompanied by electrical, thermal, chemical or other changes in the human body, which can be recorded by electronic devices and used to monitor the comfort of clothing.

Purpose. The purpose is to develop a functional system for monitoring the interlayer space of clothing given the temperature and relative humidity and for creating a prototype remote control system for clothing.

Materials and Methods. Sensors (a microcontroller with a battery, radio modules, temperature and relative humidity sensors) placed in the knitted structure of the T-shirt, on certain parts of the human body have been used. Atmega328 microcontroller equipped with 18650 batteries has been employed to detect the temperature and the relative humidity in the interlayer space of the clothing with the help of DS18B20 temperature sensors and DHT22 humidity sensors. The HC-12 radio module has been used for transmitting the data from the microcont-

roller to the target device. The data have been processed by a special program with the use of the Serial, NumPy, Matplotlib, and Drawnow libraries.

Results. *The system for remotely monitoring changes in the internal microclimate within the airspace between layers of different clothing materials has been developed. The relationship between the average temperature and the relative humidity in the interlayer clothing space has been determined and are equal to ~26 °C and 29.8%, respectively, after exposure to an outdoor temperature of −10 °C.*

Conclusions. *The obtained results can be used to improve existing and to develop new items of clothing with increased comfort.*

Keywords: microcontroller, radio module, fabrics, styling, temperature, humidity, and clothing.

The quality of a garment is determined by the degree to which various requirements are imposed on it by consumers. The complexity of consumer requirements for clothing depends on its purpose, operating conditions, and many other factors. To meet all the requirements, the clothes shall have a balanced complex of all properties.

In conditions of thermal comfort, the relative air humidity under the clothing is 35—60%. This indicator can be used to determine the ability of clothing to transfer moisture from the surface of the body to the environment. The increased humidity of the air in the interlayer clothing space has an adverse effect on the microclimate that heats up when the heat transfer from the body by evaporation slows down, and under the influence of the cold factor, when it indicates a reduced heat-shielding function. The increased humidity of an interlayer clothing space microclimate during work in the conditions of high dust and gas contamination leads to mechanical and chemical irritation of the skin and can increase the impregnation of harmful substances through the skin [1].

The air temperature of the interlayer clothing space is a function of the physical activity of the human body, so the optimal values of this indicator vary depending on the intensity of the work. For a person in a state of relative rest, a comfortable temperature in the torso area is around 30–32 °C, while during heavy physical work, this indicator drops to as low as 15 °C. Determining these parameters is achieved by studying the aforementioned indicators of the interlayer clothing space through the use of specialized sensors placed within the fabric layers [2, 3].

Therefore, when assessing the hygienic properties of clothing in terms of the air temperature in the interlayer clothing space, it is necessary to take into account the physical activity of a person and the environmental conditions. For example, when working in a cooling environment, a large drop in the air temperature directly under the outerwear indicates its low thermal resistance indicator, and when working in windy conditions, a high air permeability indicator.

The content of carbon dioxide in the interlayer clothing space above 0.8% serves as an indicator of the degree of its contamination with products of skin respiration (anthropotoxins). An increase in the content of carbon dioxide indicates insufficient ventilation of the interlayer clothing space and depends on the air permeability of the materials and the entire structure of the clothing [4].

Based on the above, it is necessary to note the great importance of the indicator of air permeability of fabrics in the development and design of special clothing for any purpose.

"Smart" textiles refers to a large field of studies and products that extend the functionality and usefulness of common fabrics. "Smart" Textiles are defined as textile products such as fibers and filaments, yarns together with woven, knitted, or non-woven structures, which can interact with the environment and user. The convergence of textiles and electronics can be relevant for the development of "smart" materials that are capable of accomplishing a wide spectrum of functions, found in rigid and non-flexible electronic products nowadays. "Smart" textiles can be divided into four subgroups:

◆ Passive "smart" textiles: able to analyze the environment and user by sensors;

◆ Active "smart" textiles: able to react to the condition or stimuli of the environment;

◆ Very "smart" textiles: able to analyze, react and adapt behavior to the given circumstances;

◆ Intelligent Textiles: able of responding or getting activated to perform a function in a manual pre-programmed manner.

"Smart" Fabrics can change or react automatically to their surroundings. These are being developed to be able to analyze parameters obtained from sensors. For example, it may help to know the heart rate spikes or drops, temperature, relative air humidity, etc. Gore-Tex can also be considered as an example of "smart" fabric because of its material properties to let water or moisture flow in one direction and not the other. Nanotechnologies such as carbon nanotubes or fireproof treatments or a combination of electronics and conductive fabrics for sensing a person's vital signs can also be considered as some modern type of "smart" fabrics. Biological monitoring technology has also been updated by mainstream consumers in the form of the Numetrex Adidas heart rate monitoring garments that combine "smart" fabrics with advanced fabrication technologies [3, 5].

In recent years, researchers from textile and electronic science have conducted many interdisciplinary studies to measure physiological parameters (temperature, humidity, heart rate, carbon dioxide, etc.), using sensors and electronic control systems integrated into the garment. These "smart" garments monitor the body and environmental signals to prevent dangerous situations [5].

Lightweight and comfortable flexible electronic "smart" textiles will certainly have wide application prospects. Currently, electronic "smart" textiles play an important role in health monitoring, disease prevention, electromagnetic protection, energy conversion, storage, human-computer interaction [6]. Taking health monitoring as an example, Victoria's Secret is a high-end lingerie brand that has launched a "smart" sports bra with a built-in heart rate sensor that tracks the wearer's heartbeat. Canadian company Hexoskin has released a new "smart" sports vest known as a "personal data laboratory" that can track heart rate, respiration, activity intensity, and other data, and provides users with data to monitor fitness, sleep, and daily activities [7]. On the one hand, it is necessary to fulfill the requirements for miniaturization of dimensions, lightness of devices, as well as flexibility and expandability of the device system itself for flexible "smart" textiles. On the other hand, it should meet the realizable requirements when the material is subjected to various mechanical deformations and external influences, and electronic devices maintain stability and operate normally. Therefore, "smart" fabrics made from electrically conductive fibers and new textile technologies have emerged. As research progresses, the benefits of 1D stretchable and flexible electrodes in devices have gradually become apparent. They are small, highly flexible, easily woven into textiles, or can be used as skin-attached portable devices. They have the characteristics of softness, elasticity, breathability, and high resistance to damage, suitable for fixing and interconnecting with electronic products. Under various tensile deformations, they can maintain contact with the human body [8].

In [5, 9], there have been presented the "smart" jacket application with an alarm that triggers when the external temperature reaches the set limit value. In this item, six silicone-encapsulated heat sensors are placed on the chest, back, and arm parts of the jacket. The controller evaluates the internal temperature signal every ten seconds until one or more sensors reach(es) 37.8 °C, after the controller monitors every sensor every second. When the internal temperature of the jacket reaches approximately 65.6 °C, an alarm is triggered. The jacket is designed for firefighters who deal with high temperature during a fire and any temperature higher than 65.6 °C is dangerous for them.

The application of "smart" textiles in clothing production includes healthcare protection, development of garments for military personnel, police officers, and emergency service workers, as well as the creation of clothing for entertainment, sports, and leisure. When "smart" textiles are used in
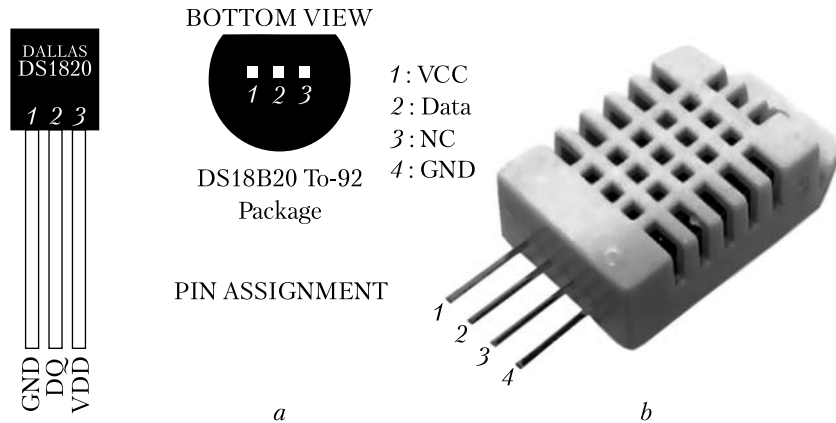
Fig. 1. Temperature sensor DALLAS18B20 (*a*) and relative air humidity sensor DHT22 (*b*): *1* — power supply voltage: 3.5–5.5 V; *2* — humidity and temperature output via serial data; *3* — not applicable as it has no connection; *4* — the sensor typically connects to the circuit ground

these areas, they exhibit properties such as light absorption, pulse measurement, and immune system indicators. Gloves with microphones, sensors in mattresses, cooling garments, heating garments, and more have already been developed today. These functions of monitoring a person's condition through clothing are achieved through the integration of sensors, conductive fibers, and other devices into the fabric structure, as well as coatings on the fabric surface [10, 11]. There is experience in using intelligent wireless sensor nodes for monitoring comfort quality in indoor spaces. The generalized structure of the distributed data collection system consists of devices for recording, processing, and storing data, data transmission, and cloud storage. Data transmission is typically the problematic part [12, 13].

In this research, the use of a remote monitoring system for changes in the internal microclimate in the air space between cloth layers has been proposed. The obtained parameters of the changes in the temperature and relative air humidity in the air space between the layers of materials of a package of clothes are important for predicting comfort indicators.

In the presented work, the prototype of a system for remote monitoring of clothing has been created with the use of a t-shirt as primary mate-
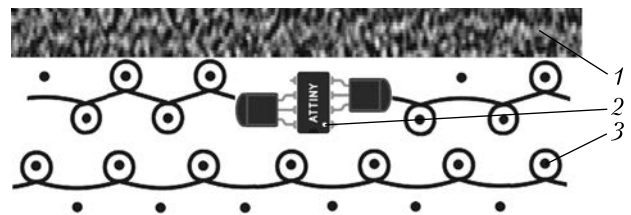
Fig. 2. Placement of sensors in the interlayer clothing space: *1* — jacket fabric; *2* — mobile module; *3* — knitwear

rial. The t-shirt's knitted structure accommodates the placement of sensors and devices for conducting research. Additionally, winter jackets are used in combination with the t-shirt during the study.

The data are collected in real-time and transmitted to a data repository with a periodicity ranging from several seconds to several tens of seconds. A wireless channel is chosen as data transmission channel, as it is the most economical solution for addressing such a task. The following equipment and devices have been used for the research: an Atmel microcontroller (Digispark ATtiny85 microUSB) equipped with a Li-Po 500 mAh 1S battery, a wireless serial port module (HC-12 wireless module), and temperature sensors DALLAS18B20 (Fig. 1, *a*) and relative air humidity sensors DHT22 (AM2302) (Fig. 1, *b*) integrated into the t-shirts knitted structure (Fig. 2).
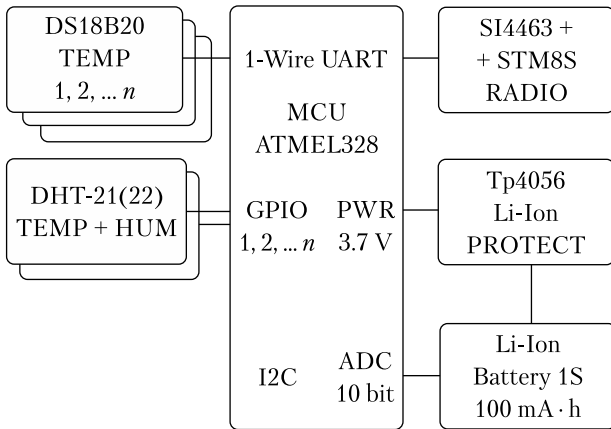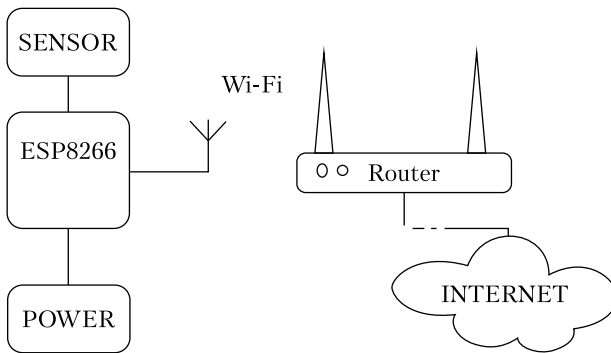
Fig. 3. Scheme of the mobile module

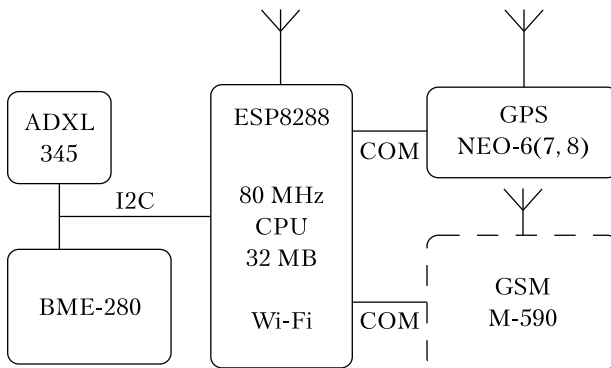**Fig. 4.** The block diagram of the moving objects survey using a WiFi network

Fig. 5. The block diagram of the moving objects survey using a GSM module

The data from the mobile module (the components of it are listed above) (Fig. 3), located in the air space between the layers of materials of a package of clothes, have been processed in real-time with the use of Python programming language and the Serial, Numpy, Matplotlib, and Drawnow libraries.

The block diagrams of moving objects survey using WiFi network (Fig. 4) and GSM module (Fig. 5) are shown below. The left side of the diagram (Fig. 4) shows the measuring terminal, on the right shows the access point through which the device connects to the cloud storage. Unfortunately, the range of signal transmission over the WiFi network is limited and does not exceed 100 m. The GSM module include ESP8288 microcontroller, GPS module and sensors.

During the conducted experiment, we have made observations on two 30-year-old individuals (males) who are examined in a state of rest and after physical exertion (walking for 10 min and running for 15 min). The chosen exercises allow for tracking the dynamics of comfort indicators in the interlayer clothing space (such as an increase in the temperature and the relative air humidity). The research is conducted during the winter season at a temperature of $-10\,°C$.

The monitoring of individuals is carried out within the range of WiFi networks. The data from the temperature and relative air humidity sensors are documented by a computer. The geodata come from a dual-speed navigator and an accelerometer. The data are saved in the flash memory or to the external flash (during the long transportation). Transmission on demand occurs periodically over a cellular channel or through open access WiFi points.

In the case when the terminal is located outside of the cellular and WiFi networks area, it is proposed to use the VHF radio channel in batch mode for data transfer to the repository. The structure of this solution include microcontroller, sensors, radio modules, battery and shown in Fig. 6.

Figure 7 shows a diagram of the data channels used in the research. The data received from sensors are transferred to the microcontroller and then through radio modules to the computer. The computer transfers data to the cloud storage where they are stored for further usage.

The temperature and the humidity in interlayer clothing space have been determined for two persons (black and red curves in the Fig. 8). From Fig. 8 we can see that for the first-person the average temperature (average temperature 1) slightly increases from 27.4 to 27.9 °C and the relative air humidity (relative humidity 1) increases from 44.8 to 46.5% when the person does physical activities (walking for 10 min). After some rest, the average temperature decreases to 24.1 °C and the relative air humidity decreases to 37.5%. After another portion of physical activities (running for 15 min), the average temperature increases to 26.2 °C and the relative air humidity to 43%. Without physical activity the temperature in interlayer clothing space decreases up to 23.1 °C and the relative air humidity almost does not change, as it slightly decreases to 40.8 and increases to 43%. The average temperature for the second-person (average temperature 2) almost does not changes and accounts for about ~ 26 °C and the relative air humidity (relative humidity 2) decreases from 43.7 to 29.8% for 2 h on the street in the winter at a
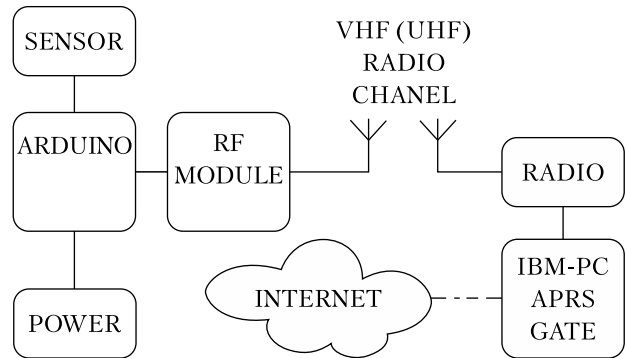

Fig. 6. Structural scheme of the system using the VHF radio network (range up to 100 km)
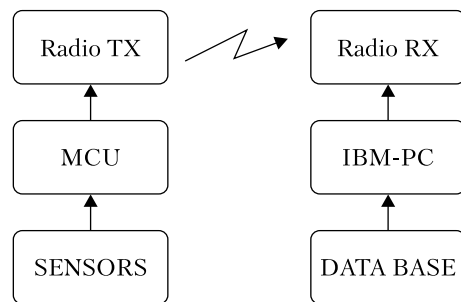

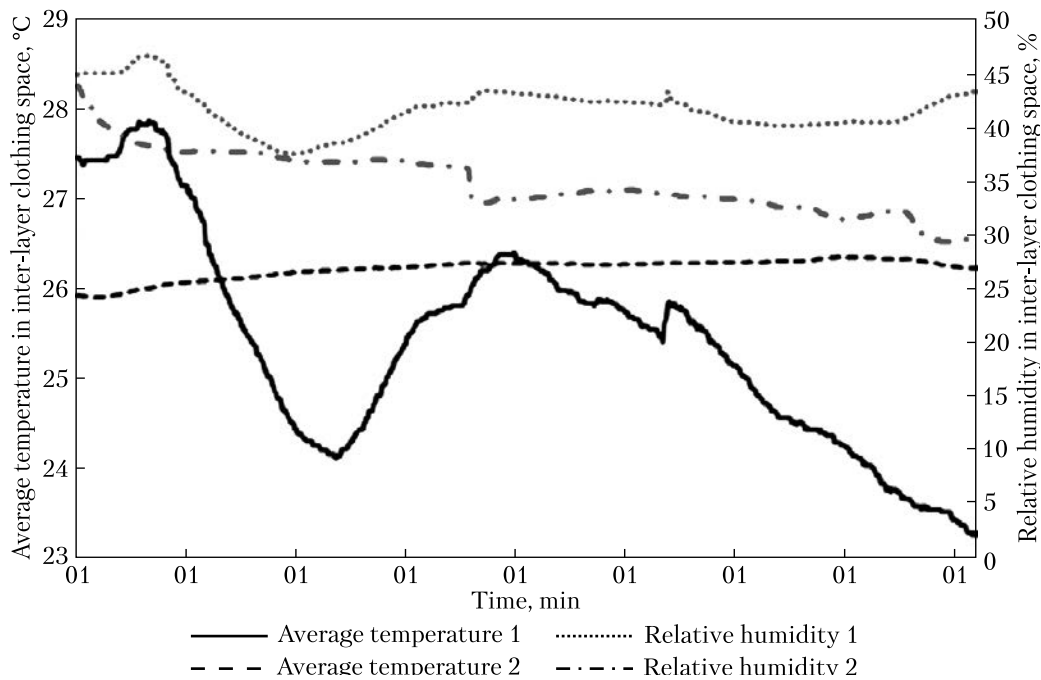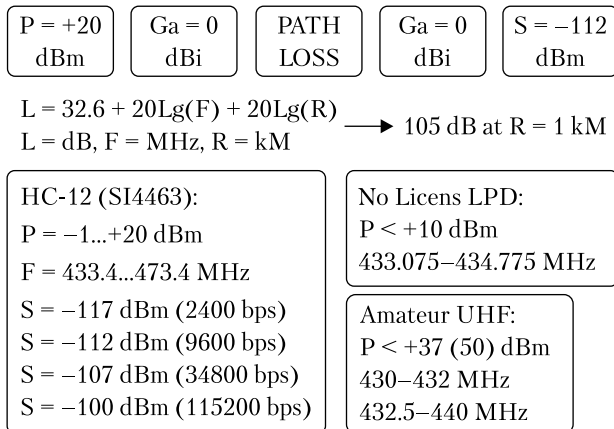**Fig. 7.** Scheme of data transmission channels

Fig. 8. Dependence of the average temperature and relative air humidity in the interlayer clothing space on time

Novak, D. S., Moshenskyi, A. O., Bereznenko, S. M., Serhiienko, L. H., and Guida, O. G.

P = +20 dBm	Ga = 0 dBi	PATH LOSS	Ga = 0 dBi	S = −112 dBm

L = 32.6 + 20Lg(F) + 20Lg(R)
L = dB, F = MHz, R = kM $\longrightarrow$ 105 dB at R = 1 kM

HC-12 (SI4463):
P = −1...+20 dBm
F = 433.4...473.4 MHz
S = −117 dBm (2400 bps)
S = −112 dBm (9600 bps)
S = −107 dBm (34800 bps)
S = −100 dBm (115200 bps)

No Licens LPD:
P < +10 dBm
433.075–434.775 MHz

Amateur UHF:
P < +37 (50) dBm
430–432 MHz
432.5–440 MHz

Fig. 9. Losses in the radio channel transmission of data from the registration devices to the data storage device

temperature ~ −10 °C. The studied persons are dressed in different types of cloth. These results could be explained by the difference in the partial pressure of water vapor between the interlayer clothing space and ambient air will decrease with increasing ambient relative air humidity, and thus the drive for evaporation will also be reduced.

When conducting research using equipment that transmits data over cellular channels, it is necessary to consider obstacles such as signal reflections from buildings, multipath effects, etc. Waves propagating between the transmitter and receiver have Fresnel zones that are determined by phase shift during reflection and subsequent transmission to the receiver. It is important to take this region into account because a sinusoidal wave passing through one of these paths may reach the receiver asynchronously and may have a significant phase shift, leading to constructive or destructive interference at the receiver [14]. In this case, it has been determined (Fig. 9) that the losses amount to 105 dB, of which 20 dB are accounted for considering "greenery" located at a distance greater than 300 m for frequencies in the 4xx MHz range, which does not affect the accuracy of the obtained data. The experiments with a power of 100 mW have been carried out under the license of the authors for the HAM radio service, call sign UT5UUV [15].

The result of the research is the development of a remote monitoring system for changing the internal microclimate in the interlayer clothing space through using sensors and microcontroller equipment. The sensors are placed in a t-shirt. Additionally, during the research, winter jackets have been used in combination with the t-shirt. The time dependencies of air temperature and relative air humidity in the interlayer clothing space have been determined.

It has been found that for the first person, the average temperature and the relative air humidity increase as a result of physical activity and the type of outerwear (jackets with natural wool insulation). The results for the second person are more stable than for the first one, as there has been reported no increase in the temperature and relative air humidity in the interlayer clothing space after exertion. Therefore, it can be concluded that the jacket with synthetic insulation is more comfortable for individuals engaged in physical activity. The research findings can be used for further improvement of existing clothing items and the development of new ones.

REFERENCES

1. Meinander, H., Honkala, M. (2004). Potential applications of smart clothing solutions in health care and personal protection. *Stud. Health. Technol. Inform.*, 108, 278—285.
2. Kurhanskyi, A., Bereznenko, S., Novak, D., Kurganska, M., Sakovets, V., Bereznenko, N., Haranina, O. (2018). Effects of multilayer clothing system on temperature and relative humidity of inter-layer air gap conditions in sentry cold weather clothing ensemble. *Vlaknaa Textil (Fibres and Textiles)*, 25(3), 43—50.
3. Saluja, M. Advancement Of Electronics In Textile — A Review. URL: https://technicaltextile.net/articles/advancement-of-electronics-in-textile-a-review-5201. (Last accessed: 20.02.2023).
4. Saluja, M. Smart Textiles — A Review. URL: https://technicaltextile.net/articles/smart-textiles-a-review-5338 (Last accessed: 20.02.2023).

5. Dursun, M., Bulgun, E., Şenol, Y., Akkan, T. (2019). A Smart Jacket Design for Firefighters. *Tekstil ve Mühendis*, 26(113), 63—70. https://doi.org/10.7216/1300759920192611307.

6. Cao, M. S., Wang, X. X., Zhang, M., Shu, J. C., Cao, W. Q., Yang, H. J., Yuan, J. (2019). Electromagnetic response and energy conversion for functions and devices in low-dimensional materials. *Advanced Functional Materials*, 29(25), 1807398. https://doi.org/10.1002/adfm.201807398.

7. Kan, C.-W.; Lam, Y.-L. (2021). Future Trend in Wearable Electronics in the Textile Industry. *Appl. Sci.* 11, 3914. https://doi.org/10.3390/app11093914.

8. Lee, J., Llerena Zambrano, B., Woo, J., Yoon, K., Lee, T. (2020). Recent advances in 1D stretchable electrodes and devices for textile and wearable electronics: materials, fabrications, and applications. *Advanced Materials*, 32(5), 1902532. https://doi.org/10.1002/adma.201902532.

9. Curone, D., Secco, E. L., Tognetti, A., Loriga, G., Dudnik, G., Risatti, M., Magenes, G. (2010). Smart garments for emergency operators: the ProeTEX project. *IEEE Transactions on Information Technology in Biomedicine*, 14(3), 694—701.

10. Zhong, Y., Zhang, F., Wang, M., Gardner, C. J., Kim, G., Liu, Y., Chen, R. (2017). Reversible humidity sensitive clothing for personal thermoregulation. *Scientific reports*, 7(1), 1—8. https://doi.org/10.1038/srep44208.

11. Kuchuk, N., Merlak, V. (2021). Modeling of information interconnection in a computer control system of moving objects. *Radioelectronic and computer systems*, 1, 31—39. https://doi.org/10.32620/reks.2022.1.03.

12. Vdovichenko, O., Perepelitsyn, A. (2021). Technologies for building systems of remote lining of communication lines: A practical example of implementation. *Radioelectronic and Computer Systems*, 2, 31—38. https://doi.org/10.32620/reks.2021.2.03.

13. Kuncoro, C. B. D., Permana, A. F., Asyikin, M. B. Z., Adristi, C. (2022). Smart Wireless Climate Sensor Node for Indoor Comfort Quality Monitoring Application. *Energies*, 15(8), 2939. https://doi.org/10.3390/en15082939.

14. Logachova, L. M., Bugrova, T. I. (2019). *The spread of terrestrial radio waves and mobile communication*. Zaporizhzhia [in Ukrainian].

15. UT5UUV-Callsign lockup. URL: https://www.qrz.com/db/ut5uuv/ (Last accessed: 20.02.2023).

Д.С. Новак[1] (https://orcid.org/0000-0002-1796-8857),
А.О. Мошенський[2] (https://orcid.org/0000-0002-4584-4958),
С.М. Березненко[1] (https://orcid.org/0000-0002-1042-6369),
Л.Г. Сергієнко[3] (https://orcid.org/0000-0002-1002-2348),
О.Г. Гуйда[4] (https://orcid.org/0000-0002-2019-2615)

[1] Київський національний університет технологій та дизайну,
вул. Немировича-Данченка, 2, Київ, 01011, Україна,
+380 44 280 5545, knutd@knutd.edu.ua

[2] Національний університет харчових технологій,
вул. Володимирська, 68, Київ, 01601, Україна,
+380 44 289 5472, info@nuft.edu.ua

[3] Державний науково-дослідний інститут МВС України,
пров. Євгена Гуцала, 4А, Київ, 03680, Україна,
+380 44 374 3406, dndekc@mvs.gov.ua

[4] Таврійський національний університет імені В.І. Вернадського,
вул. Джона Маккейна, 33, Київ, 01042, Україна,
+380 44 529 0516, crimea.tnu@gmail.com

ФУНКЦІОНАЛЬНА СИСТЕМА ДЛЯ МОНІТОРИНГУ ТЕМПЕРАТУРИ ТА ВІДНОСНОЇ ВОЛОГОСТІ ПОВІТРЯ У ПІДОДЯГОВОМУ ПРОСТОРІ

Вступ. Дослідження параметрів підодягового простору є вкрай важливим при розробці сезонного одягу для військових, поліцейських, спортсменів та ін.

Проблематика. Заслуговує на увагу застосування «розумного» текстилю, здатного реагувати на зміни у навколишньому середовищі, адаптуватися до нього шляхом інтеграції функціональних можливостей текстильної структури. Почуття і навіть емоційна реакція людини супроводжується електричними, тепловими, хімічними чи іншими змінами в організмі людини, які можуть бути зафіксовані електронними приладами та використовуватися для моніторингу комфортності одягу.

Мета. Розробка функціональної системи моніторингу міжшарового простору одягу з урахуванням температури й відносної вологості та створення прототипу системи дистанційного контролю за одягом.

Матеріали й методи. Застосовано датчики, які розміщено на певних ділянках тіла людини; мікроконтролер з акумулятором, радіомодулі, датчики температури та відносної вологості, розміщені у трикотажній структурі футболки. Використано мікроконтролер Atmega328, оснащений акумуляторами 18650, для визначення температури та відносної вологості у міжшаровому просторі одягу за допомогою датчиків температури DS18B20 та датчиків вологості DHT22. Для передачі від мікроконтролера до цільового пристрою задіяно радіомодуль HC-12. Дані оброблено спеціальною програмою з використанням бібліотек *Serial, NumPy, Matplotlib* та *Drawnow*.

Результати. Розроблено систему дистанційного моніторингу змін внутрішнього мікроклімату в повітряному просторі між шарами матеріалів різного одягу. Досліджено залежності середньої температури та відносної вологості у міжшаровому просторі одягу, які становить близько ~26 °C, та 29,8 % відповідно після перебування на вулиці при температурі −10 °C.

Висновки. Отримані результати можуть бути використані для вдосконалення наявних та розробки нових предметів одягу підвищеної комфортності.

Ключові слова: мікроконтролер, радіомодуль, тканини, дизайн, температура, вологість, одяг.