https://doi.org/10.31891/2307-5732-2025-349-39
УДК 687.016:004.8:331.45:621.9.048

MYTSA VIKTORIIA
Khmelnytskyi National University
https://orcid.org/0000-0002-5453-9787
e-mail: mitsa_vv@ukr.net
RIABCHYKOV MYKOLA
Lutsk National Technical University
https://orcid.org/0000-0002-9382-7562
e-mail: mykola.riabchykov@lntu.edu.ua

THE USE OF ARTIFICIAL INTELLIGENCE TO DEVELOP EFFECTIVE PROTECTIVE CLOTHING SOLUTIONS

The object of the research is the development of intelligent algorithms for creating protective clothing using artificial intelligence (AI) systems. The main attention is paid to the integration of active and passive smart devices into the structure of protective materials, as well as the optimization of the process of their development using mathematical methods. Traditional methods of designing protective products are resource-intensive and do not always guarantee optimal results. The problem of ensuring effective protection against harmful factors in production environments is particularly acute. Existing AI algorithms have limitations in the correct formulation of the problem and the selection of the optimal solution.

During the study, two groups of parameters were identified that affect the process of designing protective solutions. The first group determines dangerous factors (mechanical, temperature, electromagnetic, chemical, etc.), the second - the capabilities of modern protective materials and devices. Formalized approaches based on mathematical logic are proposed to optimize the process of creating protective products. An iterative algorithm with three feedback loops has been developed, which allows to increase the efficiency of the AI system.

The results obtained are due to the implementation of logical-mathematical methods for formalizing design solutions. Optimization of the algorithm through feedback helps to reduce the number of iterations required to obtain an effective design to 1–3 cycles.

The proposed algorithms can be integrated into industrial systems for automated design of protective products that meet modern safety requirements. Potential areas of application are the production of special clothing, personal protective equipment, as well as the development of smart systems for monitoring harmful factors in industry.

Keywords: artificial intelligence, protective clothing, algorithm, smart devices, harmful production factors.

МИЦА ВІКТОРІЯ
Хмельницький національний університет
РЯБЧИКОВ МИКОЛА
Луцький національний технічний університет

ВИКОРИСТАННЯ ШТУЧНОГО ІНТЕЛЕКТУ ДЛЯ РОЗРОБКИ ЕФЕКТИВНИХ РІШЕНЬ ЗАХИСНОГО ОДЯГУ

Об'єктом дослідження є розробка інтелектуальних алгоритмів для створення захисного одягу з використанням систем штучного інтелекту (ШІ). Основну увагу приділено інтеграції активних і пасивних інтелектуальних пристроїв у структуру захисних матеріалів, а також оптимізації процесу їх розробки математичними методами. Традиційні методи розробки захисних виробів є ресурсомісткими і не завжди гарантують оптимальні результати. Особливо гостро стоїть проблема забезпечення ефективного захисту від шкідливих факторів у виробничих середовищах. Існуючі алгоритми ШІ мають обмеження в правильній постановці задачі та виборі оптимального рішення.

Під час дослідження виділено дві групи параметрів, які впливають на процес проєктування захисних виробів. Перша група визначає небезпечні фактори (механічні, температурні, електромагнітні, хімічні та ін.), друга – можливості сучасних захисних матеріалів і пристроїв. Для оптимізації процесу створення захисних виробів запропоновано формалізовані підходи на основі математичної логіки. Розроблено ітераційний алгоритм з трьома циклами зворотного зв'язку, що дозволяє підвищити ефективність системи ШІ.

Отримані результати обумовлені реалізацією логіко-математичних методів формалізації проектних рішень. Оптимізація алгоритму за допомогою зворотного зв'язку допомагає скоротити кількість ітерацій, необхідних для отримання ефективного дизайну, до 1–3 циклів.

Запропоновані алгоритми можуть бути інтегровані в промислові системи автоматизованого проєктування засобів захисту, які відповідають сучасним вимогам безпеки. Потенційними сферами застосування є виробництво спеціального одягу, засобів індивідуального захисту, а також розробка розумних систем моніторингу шкідливих факторів у промисловості.

Ключові слова: штучний інтелект, захисний одяг, алгоритм, розумні пристрої, шкідливі виробничі фактори.

Introduction

Artificial intelligence (AI) technologies are rapidly evolving, opening up new avenues of application across various fields of science and technology [1]. In addition to traditional areas of application, AI is actively used for the creation of intelligent design systems [2], enabling the automation of complex engineering object development processes, including clothing design. Modern software tools allow the use of AI for creating garments tailored to individual requirements [3, 4]. However, the implementation of such systems does not always guarantee efficiency, especially in environments where a high level of protection from harmful industrial factors is required [5].

Traditional methods of creating protective equipment [6] are often cumbersome, resource-intensive, and do not always ensure optimal design. The task of designing protective clothing, which must meet safety, efficiency, and user comfort standards, becomes particularly critical. Recommended methods for designing such items [7] require high qualifications from designers and a significant amount of time for implementation. The use of AI in combination with digital algorithms significantly simplifies the process of creating protective clothing [8], but also presents new challenges, particularly regarding the correct formulation of tasks and decision-making.

In modern conditions, 3D modeling technologies play a key role, contributing to more accurate calculations and optimization of protective clothing characteristics [9, 10]. However, shortcomings in the formulation of design tasks can lead to errors, which may result in dangerous situations in protective clothing.

Thus, there is an urgent need to resolve the contradiction between the necessity of creating effective protective equipment and the limitations of existing algorithms, which fail to provide optimal solutions. This calls for the application of new AI-based approaches to develop effective protective systems.

The purpose of the paper is to substantiate algorithms for using artificial intelligence to create effective protective equipment, considering the design features and user needs.

Methods

The traditional methodology for creating protective clothing is based on simplified algorithms that implement protection against the main hazards described in [11]. These factors include mechanical, thermal, and electromagnetic influences, which determine specific requirements for protective equipment. These requirements set the basic parameters that are implemented as features when creating protective clothing. Such features are determined by the materials used, design characteristics, and additional elements that affect parameters such as thermal conductivity, breathability, comfort, and ease of use.

A structural approach to designing protective clothing includes consideration of the main characteristics of each hazard, allowing for the selection of appropriate materials and the development of designs that provide effective protection. Fig. 1 shows a simplified diagram illustrating the basic structure of an intelligent system for creating protective clothing.

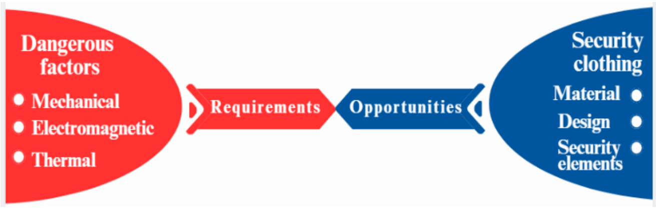

Fig. 1. Simplified structure of an intelligent system for creating protective clothing

The basic algorithm of using artificial intelligence on a number of platforms such as Deep Dream Generator, Midjourney, DreamStudio, LeonardoAI includes the stages of creating and refining textual prompts, entering the initial data into the system, iterating to create the desired product, and making refinements at each step [12]. Although this approach is useful for generating initial ideas, its application to the development of protective clothing does not always lead to optimal solutions. This is due to the limitations of simplified algorithms and the inability to fully take into account complex safety requirements.

To evaluate the rational parameters of the created product, interviews and questionnaires were conducted in focus groups. The participants of these groups were representatives of the garment industry, specialists from occupational health and safety departments of enterprises, researchers and teachers of higher education institutions. The interviews collected data on the potential effectiveness of AI-designed protective clothing and assessed the technological feasibility and practical implementation of such systems.

The results of these surveys point to the importance of improving existing algorithms. The use of AI methods can significantly reduce development time and reduce resource costs, but further refinement of the system and integration of more complex algorithms capable of taking into account the full range of requirements for protective clothing is required to achieve optimal solutions.

Results

Preliminary analysis of the functioning of artificial intelligence systems indicates the need for a clear task formulation for designing protective clothing. To achieve maximum AI efficiency, an algorithm must be developed that accounts for detailed and structured initial information, enabling AI to accurately process data and generate appropriate solutions.

The foundation for creating an advanced algorithm is a specific structure that reflects hazardous working conditions, as well as the requirements for protective clothing dictated by these conditions. The first step is the analysis of harmful production factors, followed by the assignment of corresponding designations. Based on source research, the key harmful factors affecting the design of protective clothing have been identified. These include:

- Vibration (D_1), which is classified as follows:
- By frequency: high frequency (D_1^1), medium frequency (D_1^2), low frequency (D_1^3);
- By impact structure: whole-body vibration (D_1^4) and localized vibration (D_1^5), where localized vibration can further be specified by the area of impact on the human body (D_1^{51} – hands, D_1^{52} – feet, D_1^{53} – torso).
- Radiation (D_2), is classified as follows:

- By frequency: alpha (D_2^1), beta (D_2^2), gamma (D_2^3);
- By intensity: low (D_2^4), medium (D_2^5), high (D_2^6).
- Electromagnetic fields (D_3), which include:
- Electric field (D_3^1), magnetic field (D_3^2), and radio waves (D_3^3);
- By intensity: low (D_3^{41}), medium (D_3^{42}), high (D_3^{43}).

Other harmful factors include fire and explosions (D_4), toxic substances (D_5), mechanical impact from equipment (D_6), temperature (D_7), pollution (D_8), biological factors (D_9), and mechanical damage (D_{10}). All these factors can similarly be classified by frequency, intensity, or area of impact.

Different harmful factors may be interrelated or influence one another. Some of them may be incompatible, while others may act in combination, requiring a more complex approach to the design of protective clothing. To formalize the interaction of hazardous factors, the following logical operators are used:

$\wedge$ - logical conjunction ("and"),

$\vee$ - logical disjunction ("or"),

$\neg$ - logical negation ("not"),

□ - logical implication ("if... then").

The symbolic notation of factors can be represented as follows:

$D= D_{51}^1 \rightarrow(D_{62}^{12} \wedge D_{91}^2 \vee (D_{1222} \wedge D_{23}^3) \vee D_7 \neg D_8).$

The counter group of characteristics defines the ability of protective equipment to perform its functions under specific conditions. It is important to note that in modern conditions, some effective tools are used to ensure reliable worker protection. The main groups of protective means may include:

- Special materials (group O_1);
- The design of the protective product (group O_2);
- Passive smart devices for monitoring and recording harmful factors (group O_3);
- Active devices are capable of influencing the state and functioning of the protective product (group O_4).

The material properties that affect their protective characteristics include:

- Material density (O_1^1): Influences the ability to resist temperature, radiation, and other factors;
- Heat resistance (O_1^2): Determines the ability of textile materials to function under elevated temperatures;
- Chemical resistance (O_1^3): Defines the ability to operate in aggressive environments;
- Wear resistance (O_1^4): Besides protective properties, it also impacts the overall durability of the product;
- Water resistance (O_1^5): Determines the ability to operate in wet environments;
- Product color (O_1^6): In some cases, color can be a critical factor influencing visibility.

The group of properties that defines the construction of the product influences its structure's ability to provide protective functions. The fit and form of the garment (O_2^1) can affect thermal protection properties and comfort levels. Additional clothing elements (O_2^2) are capable of significantly enhancing its protective functions. An additional outer layer made of special material (O_2^3) can also improve the effectiveness of the garment. In some cases, fastening elements and adjustments to the garment's construction (O_2^4) can improve its overall quality. Special finishing (O_2^5) can alter the garment's performance to enhance its characteristics.

The recent surge in the development of new electronic devices has created conditions for the design of smart systems, including smart clothing. These devices can be broadly divided into passive, which record certain parameters, and active, which can control these parameters. Passive devices include various sensors, such as temperature sensors, location sensors, waste sensors, and moisture sensors. This group also includes electronic data storage and transmission devices, such as NFC or RFID tags. The proposed designations for passive smart devices can be labeled as O_3^1, O_3^2, O_3^3, O_3^4, O_3^5, O_3^6.

Active smart devices, in some cases, allow for controlled water absorption, which enhances comfort, as well as energy generation, which increases the autonomy of protective equipment.

Modern textile materials have the capability to regulate temperature, ensuring comfortable working conditions in various environments. This enables their use in protective equipment adapted to changing thermal conditions. Some smart textile materials may also possess bacteriostatic or therapeutic effects, which enhance the level of protection and hygiene of the products. The ability of materials to change color opens up possibilities for creating items that can display warning signals or mimic the surrounding environment for camouflage purposes.

The combination of material property systems can be represented in a formalized manner using the proposed notations and logical operations:

$O=\{(O_{11} \wedge\vee O_{12} \wedge\vee O_{13} \wedge\vee O_{14} \wedge\vee O_{15} \wedge\vee O_{16}) \wedge\vee(O_{21} \wedge\vee O_{22} \wedge\vee O_{23} \wedge\vee O_{24} \wedge\vee O_{25}) \wedge\vee(O_{31} \wedge\vee O_{32} \wedge\vee O_{33} \wedge\vee O_{34} \wedge\vee O_{35}) \wedge\vee(O_{41} \wedge\vee O_{42} \wedge\vee O_{43} \wedge\vee O_{44} \wedge\vee O_{45})\}.$

The obtained system of features allows for the creation of advanced prompts for the functioning of artificial intelligence systems. The enhanced capability structure, which can be used in formulating requirements for the operation of an AI system, is presented in Fig. 2. The use of universal logical formulas enables the algorithmization of the prompt creation process, simplifying its interpretation by AI systems and improving the efficiency of their functioning for the development of protective equipment in an interactive mode.

The developed approach serves as the foundation for the artificial intelligence (AI) interaction algorithm. The overall algorithm for using AI in clothing design consists of several stages.

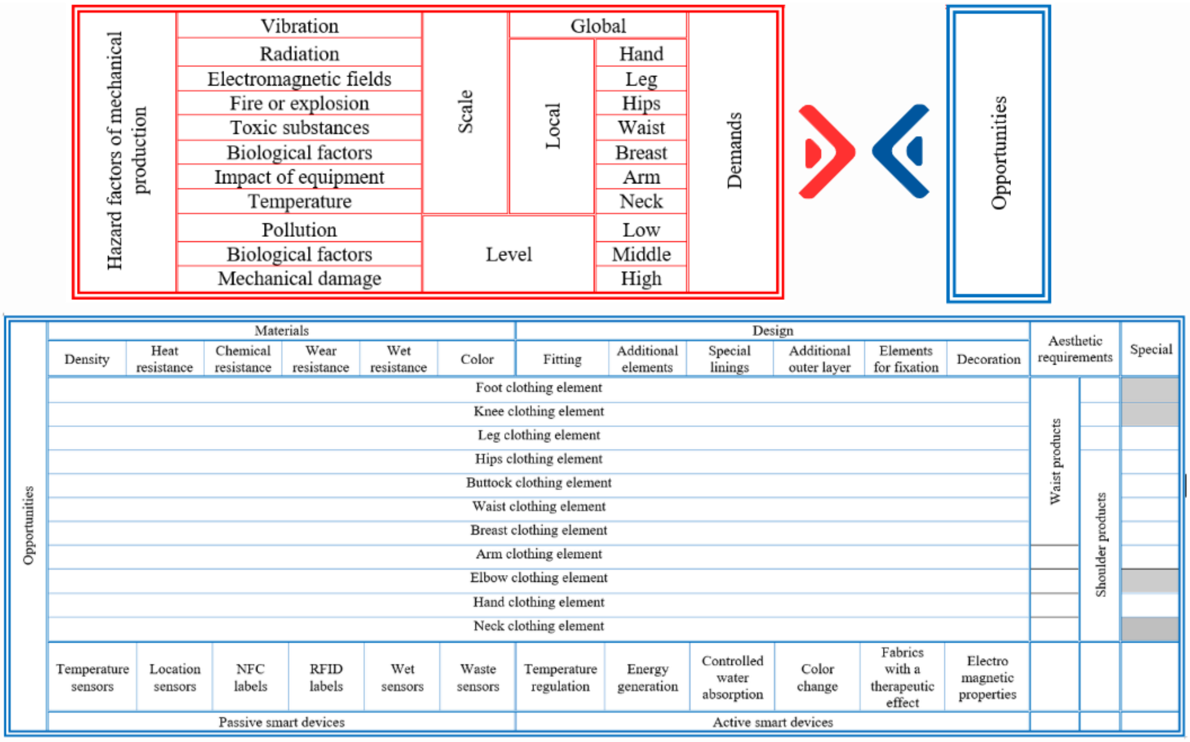

Fig.2. Improved structure of the intelligent system for the creation of protective clothing

In the first stage, a dataset of clothing images is gathered, and data on current trends and consumer preferences is collected. Data preparation involves classifying images based on clothing type, style, color, and other characteristics relevant for further analysis. After data preparation, generative models are created and trained to generate new clothing designs. Additionally, trend analysis models are developed to identify current trends and forecast demand for specific styles or clothing features.

Utilizing the generated data, AI models create new clothing concepts while taking into account production constraints and materials. The generated designs are evaluated for their potential, and the best options are selected for further development. The selected concepts are tested with focus groups, expert surveys are conducted, and feedback is gathered to improve the AI models further. After releasing new clothing models, sales performance and customer feedback are tracked, allowing an assessment of the created designs' success and adjustments to the algorithm if needed. This algorithm combines AI creativity with designers' expertise to foster innovative and competitive clothing.

The generalized algorithm for designing protective clothing based on feature function systems is structured as an iterative process (Fig. 3) with three feedback loops. The first iterative loop regulates the interaction with the primary feature system, which identifies requirements for protection against hazardous factors. At this stage, in interaction with the AI system, the capabilities of existing protective measures are assessed, and a prompt is generated for further use in the graphical module of the AI system. If reliable protection cannot be ensured with existing means, it is recommended to reduce the operational requirements or shorten the duration of use.

The second feedback loop controls the process of developing the graphical solution. Here, the formalized description of functional capabilities should approximate the formalized requirements. In case of discrepancies, it is necessary to return to the textual prompt to analyze the alignment of specific requirement elements and capabilities. Special attention should be given to the use of passive and active smart technologies, as well as AI queries to explore new smart systems and approaches.

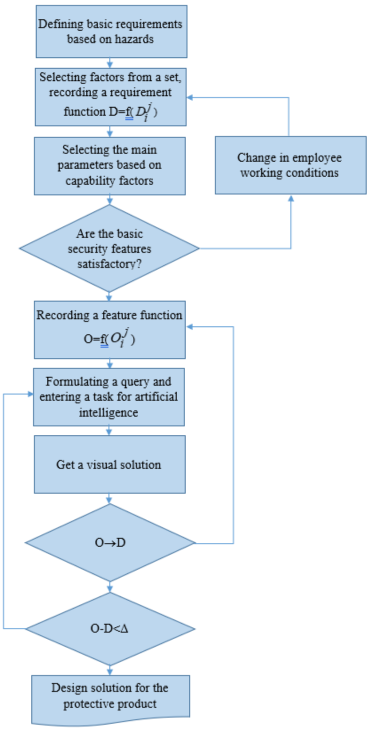

Fig. 3. A generalised algorithm for using artificial intelligence to create protective equipment

The third iterative loop involves expert participation to evaluate the degree to which the obtained solution meets the formalized requirements.

The overall results of applying the proposed approach at the initial stage demonstrated significant visual advantages of the created designs (Fig. 4). A reduction in the number of iterations between the operator and the AI system was also noted, from 6-7 to 2-3, which allowed for substantial optimization of the design development process.

Fig. 4. Result of using the advanced algorithm in the creation of protective clothing

Taking into account the generated designs of protective clothing, prototypes of a men's jacket and overalls were created, which are shown in Fig. 5.

Fig. 5. Prototypes of a men's jacket and overalls

Trial products were sewn, made according to the proposed algorithm. They were compared with standard protective clothing available at enterprises. To evaluate the protective clothing based on key efficiency parameters, a survey was conducted among groups of experts. The questionnaire included questions regarding the main parameters of protective clothing, such as the level of protection against harmful factors, comfort and convenience during use, material durability, and performance in challenging conditions. Experts were asked to rate the effectiveness of the protective clothing on a five-point scale, where five represented the highest score. The results obtained indicate that the proposed approach using an advanced artificial intelligence algorithm contributes to the creation of more effective protective clothing. The developed designs of a men's jacket and overalls demonstrate a high level of protection, ease of use and long-term operation in difficult conditions. The use of artificial intelligence can significantly reduce the number of iterations in design development, which helps to optimise the design process. The results of the expert survey confirm the advantages of using an advanced algorithm over simplified methods, ensuring a high level of satisfaction of key requirements for protective clothing.

Conclusions

To improve the effectiveness of artificial intelligence systems in the development of protective solutions, two complementary feature systems were created. The first system of requirements encompasses a set of harmful factors and currently includes 9 main groups, each containing 5 to 10 elements. The second system of capabilities consists of 4 groups, each with 5-6 elements. Both systems remain open for further enhancement and development.

The feature system is formalized using logical operators, which enables a clear structuring of requirements and capabilities for effective use with AI graphic systems. This approach facilitates the creation of an efficient prompt necessary for working with AI-based graphic systems.

The enhanced AI algorithm for creating protective solutions against harmful factors includes three feedback loops, which significantly reduce the number of required iterations to 1-3. According to expert survey results, the effectiveness of the generated protective solutions has significantly improved: the average effectiveness score increased, indicating the high efficiency of the proposed approach.

References

1. Baruah R.D., Organero, M.M. (2024) Explicit Context Integrated Recurrent Neural Network for applications in smart environments. Expert Systems with Applications, 255, D, 124752. https://doi.org/10.1016/j.eswa.2024.124752.

2. Liu X., Hao Y., Zhao L., Liu G., Sheng V.S., Zhao P. (2024) LMACL: Improving Graph Collaborative Filtering with Learnable Model Augmentation Contrastive Learning. ACM Transactions on Knowledge Discovery from Data, 18(7), 177. https://doi.org/10.1145/3657302.

3. Riabchykov M., Mytsa V., Ryabchykova K. (2024). Artificial Intelligence as a Tool for the Development of Professional Competencies of a Fashion Industry Specialist. In: Faure, E., et al. Information Technology for Education, Science, and Technics. ITEST 2024. Lecture Notes on Data Engineering and Communications Technologies, 222. Springer, Cham. https://doi.org/10.1007/978-3-031-71804-5_20.

4. Movchanuk A., Mytsa V. (2024). Creating a collection of clothes using artificial intelligence**.** Conferinţa tehnico-ştiinţifică a studenţilor, masteranzilor şi doctoranzilor – Technical Scientific Conference of Undergraduate, Master and PhD Students, 27-29 martie 2024. Universitatea Tehnică a Moldovei. Vol. 4, pp. 2142-2146. http://repository.utm.md/handle/5014/27999.

5. Abikenova S., Issamadiyeva G., Kulmagambetova E., Daumova G., Abdrakhmanova N. (2023). Assessing occupational risk: a classification of harmful factors in the production environment and labor process. International Journal of Safety and Security Engineering, 13, 5, 871-881. https://doi.org/10.18280/ijsse.130511.

6. Kozlovszky M., Pavlinić D.Z., Oder A., Fehér G., Bogdanov P. (2015). Situation and location awareness in harsh environment. 2015, 38th International convention on information and communication technology, electronics and microelectronics (MIPRO), Opatija, Croatia, 328-332. https://doi.org/10.1109/MIPRO.2015.7160288.

7. Ostapenko N., Kolosnichenko M., Tretiakova L., Lutsker T., Pashkevich K., Rubanka A., Tokar H. (2021). Definition of the Main Features of Material Assemblies for Thermal Protective Clothing During External High-temperature Effect Modelling. Tekstilec, 64(2), 136-148. https://doi.org/10.14502/Tekstilec2021.64.136-148.

8. León R., Alvarez P., Cavero A., Espinoza V., Quiroz F. (2024). Development of a Personal Protective Equipment Detection Algorithm Using Computer Vision with Python in State School Construction Sites. In: Iano, Y., et al (eds) Proceedings of the 9th Brazilian Technology Symposium (BTSym'23). BTSym 2023. Smart Innovation, Systems and Technologies, 402. Springer, Cham. https://doi.org/10.1007/978-3-031-66961-3_4.

9. Riabchykov M., Mytsa V., Bondarenko M., Popova T., Nechipor S., Nikulina A., Bondarenko S. (2023). Formation of complex 3D surfaces scans for garment CAD, Vlakna a Textil, 30(3), 13-18. http//doi.org/10.15240/tul/008/2023-3-002.

10. Polishchuk A., Slavinska A., Polishchuk O., Mytsa V. (2023). Production of details of difficult designs of footwear and clothes with use of technologies of additive production. *AIP CONFERENCE PROCEEDINGS.* 7 December 2023; 2889 (1): 040009. https://doi.org/10.1063/5.0172971.

11. Li K., Jia W., Li Z. (2024). Regulation of Appropriate Prompts for Users in Text-Based Generative Artificial Intelligence Programs. Software: Practice and Experience. https://doi.org/10.1002/spe.3389.

12. Li H., Shi L. (2024). Applied research on the design of protective clothing based on the Kano-QFD-PUGH method. PLOS ONE, 19. https://doi.org/10.1371/journal.pone.0312045.