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AUTOMATED CAMOUFLAGE DESIGN BASED ON ARTIFICIAL INTELLIGENCE

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Abstract**—*The article discusses the development of a camouflage uniform production system for civilian use with an emphasis on survival and hunting. Effective camouflage requires precise reproduction of the colors, textures, and patterns of specific landscapes, increasing hunting success and unnoticed movement. The technological process of fabric dyeing, necessary for the production of high-quality camouflage uniforms, includes fabric preparation, dyeing and strict quality control.. Fabric preparation includes cleaning, soaking, bleaching, and mercerization to ensure uniform dye absorption and durability. Dyeing methods vary by fabric type, with reactive dyes for natural fibers and disperse dyes for synthetics. Quality control includes visual inspections and tests for colorfastness under various conditions. Advanced dyeing techniques such as continuous dyeing, spray dyeing, stencil dyeing and digital printing have been analyzed to offer certain advantages. Machines like the Mimaki TX300P handle various fabric widths with high precision and reliability, enhancing efficiency. Automation using the Mimaki TX300P streamlines the dyeing process, optimizing ink consumption and integrating fabric loading, printing, and cutting systems. A customer relationship management system further automates garment creation, enhancing design, order management, and quality control. Tools like CLO3D enable detailed 3D modeling and accurate pattern reproduction. The customer relationship management system coordinates production stages and provides precise paint usage recommendations, ensuring efficient resource management and high-quality outcomes. In conclusion, developing and automating fabric dyeing processes for camouflage uniforms involve advanced technologies and meticulous quality control, ensuring durable, colorfast camouflage clothing that blends effectively into natural environments for civilian use.*

Index Terms—Technological process of fabric dyeing; generative-competitive network camouflage pattern; customer relationship management; artificial Intelligence; automated design; quality control.

I. INTRODUCTION

The creation of camouflage uniforms is particularly relevant in civilian life, especially in the context of survival in the wild and hunting. Camouflage clothing allows a person to blend into the surrounding environment, which is critically important for ensuring safety and efficiency while in forests where potential dangers, such as predators, may lurk. Additionally, for hunters, camouflage is indispensable as it allows them to approach wild animals at a safe distance without the risk of being detected. Effective camouflage requires the precise reproduction of colors, textures, and patterns characteristic of a specific landscape, increasing the chances of success in hunting or unnoticed movement in a natural environment. Therefore, the development of camouflage uniforms becomes an important task aimed at ensuring the maximum adaptation of clothing to the conditions of the locality.

II. DESCRIPTION OF THE TECHNOLOGICAL PROCESS OF FABRIC DYEING

The technological process of fabric dyeing is one of the primary stages in the production of camouflage and includes several key phases that allow achieving the desired coloration and properties of the material. Special attention during dyeing is given to the choice of fabric, the use of dyes, and quality control methods.

One of the most important stages in the dyeing process is fabric preparation. It includes cleaning the material from natural and artificial contaminants that can affect the uniformity and quality of dyeing. Preparation usually includes soaking, bleaching, and mercerization, which improves the fabric's ability to absorb dyes and ensures color durability.

Next is the actual dyeing process. The choice of dyeing method depends on the type of fabric, the desired effect, and the properties of the dyes. For example, for natural fibers such as cotton or linen, reactive dyeing is often used, providing bright and durable colors. Synthetic materials, such as polyester, are usually dyed with disperse dyes, which form thermal bonds with the fabric.

The dyeing production structure also includes a quality control system. This can be a visual inspection for defects as well as instrumental measurement of colorfastness under operating conditions, including tests for lightfastness, abrasion resistance, and color changes under the influence of sweat or water. This ensures the high quality of the final product and its compliance with consumer requirements.

For dyeing camouflage clothing, fabrics with special properties, such as polyester or nylon, are often used because they support complex patterns well and ensure durability under harsh conditions. Cotton and synthetic fiber blends, which combine comfort and practicality, are also popular.

The dyeing process itself begins with dissolving the dyes in water or another solvent, followed by their combination with the fabric. The interaction of dye with fabric depends on the chemical nature of both components. The dye can enter into a chemical reaction with the fibers, forming stable bonds, or settle on the surface as a thin layer, which also ensures color durability.

The quality of dyeing is measured using various tests, including the analysis of coating uniformity, water resistance checks, abrasion resistance, and the ability to retain color after multiple washes. These parameters help ensure that the dyed fabric meets all the requirements set by consumers and production standards.

III. Overview of Existing Solutions in Clothing Dyeing

Existing methods of garment dyeing include continuous dyeing, spray dyeing, stencil dyeing, and digital printing.

1) Continuous dyeing is a process in which the fabric is continuously moved through a dye bath or under dyeing units. The fabric first passes through a series of rollers to remove excess water and dye, followed by drying and thermofixation. This method is efficient for large batches of fabric and allows for quick processing of the material.

2) Spray dyeing uses special pumps that spray dye onto the fabric through nozzles positioned at a certain height above the material. This method allows precise control of the amount of dye applied and ensures high-quality coloring, especially when using complex patterns.

3) Stencil dyeing involves the use of flexible stencils (templates) through which dye is applied to specific areas of the fabric. This method allows for the creation of detailed and accurate patterns. The fabric can be stretched on a frame to ensure even application of the dye.

4) Digital printing is a modern dyeing method in which the image is transferred directly from digital files to the fabric using inkjet technology. Digital printing allows for photorealistic coloring with an unlimited color range. The dye is applied by micro-droplets sprayed onto the material, ensuring color accuracy and sharpness of the design.

In the field of industrial fabric dyeing, various types of machines are used, including rotary and flatbed printing machines for stencil dyeing, units for continuous dyeing, spray systems, and digital printing machines. Each type of machine has its features and is adapted to specific tasks. For example, digital printing machines are often branded as Mimaki, which are leaders in their segment due to their high precision, reliability, and efficiency.

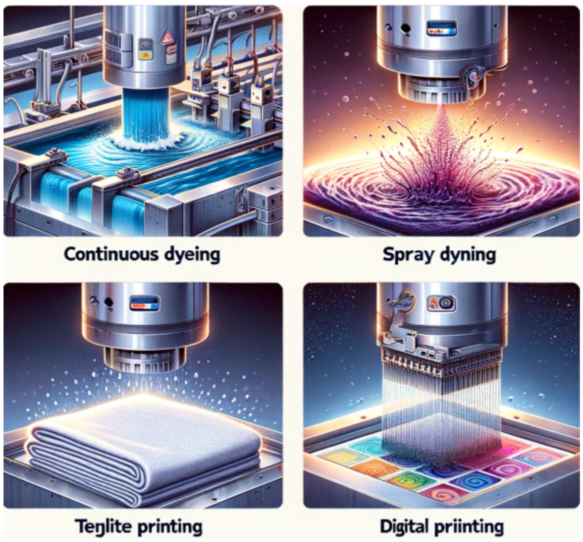

Fig. 1. Different Types of Dye Application on Fabric

Let's consider the process of automating dyeing using the Mimaki TX300P.

Mimaki TX300P is a high-performance textile printer designed for direct digital printing on fabrics. One of the key features of this device is its ability to handle fabrics of various widths [8]. The maximum print width that the Mimaki TX300P can process is 1940 mm, making it ideal for large textile projects such as producing a complete set of camouflage clothing.

This printer offers high precision and reliability, ensuring that patterns and colors are consistently applied across the entire fabric. Its digital printing capabilities allow for intricate and complex designs, which are essential for creating effective camouflage patterns. Moreover, the use of digital files for printing enables quick adjustments and customization, catering to specific requirements and reducing lead times in production.

The automation provided by the Mimaki TX300P streamlines the dyeing process, reducing manual intervention and increasing efficiency. This not only enhances productivity but also ensures consistent quality across different batches of fabric. With features such as high-speed printing and advanced ink technology, the Mimaki TX300P ensures that the final product meets the highest standards of durability and colorfastness required for camouflage clothing (Fig. 2).

Fig. 2. Mimaki TX300P

Regarding ink consumption, the TX300P is optimized for economical use of materials. The ink consumption depends on the type of fabric and the images being printed, but generally, it can range from 4 to 10 ml per square meter. This allows for maintaining high print quality while efficiently using ink. The ink containers in the printer can hold up to two liters of ink for extended continuous printing, reducing the need for frequent refills and optimizing the workflow.

The fabric loading process in the Mimaki TX300P is designed for maximum simplicity and efficiency. The fabric is loaded onto an input spool and automatically unwound through a tension control system that ensures even and accurate feeding of the material under the print heads. After printing, the fabric goes through a thermal processing stage in the built-in fixer, which secures the dye onto the fabric, ensuring its durability and brightness.

After printing and thermal processing, the fabric can be automatically cut into the required panels using an integrated cutting system, which can be configured according to the specific project's requirements. This process not only simplifies further fabric processing but also reduces production time, as the entire process from printing to panel preparation occurs within a single piece of equipment.

Overall, the Mimaki TX300P is an advanced solution for those seeking high performance, quality, and flexibility in textile printing, providing high-quality coloring with optimal resource utilization.

IV. AUTOMATION OF THE GARMENT CREATION PROCESS THROUGH A CUSTOMER RELATIONSHIP MANAGEMENT SYSTEM

For creating camouflage clothing, it is particularly important to approach the design stage correctly. One of the modern tools for this is clothing design software, specifically CLO3D [7]. This garment editor allows detailed work on every aspect of clothing, from visualization to pattern cutting. Using CLO3D enables the creation of three-dimensional models of clothing, which is crucial for accurately reproducing camouflage patterns and their subsequent adaptation to production processes. The software includes features for simulating draping, textures, and material interactions, allowing for high-quality and realistic end products (Fig. 3).

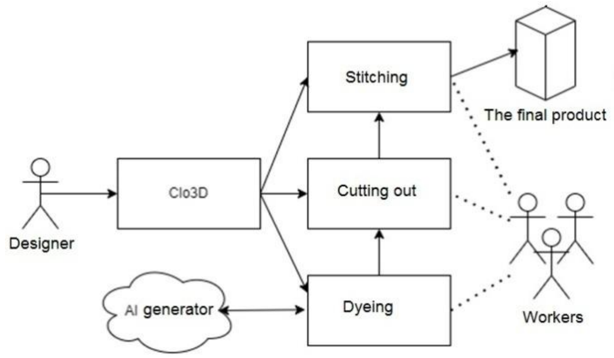

Fig. 3. Automated painting process

Automation of the fabric dyeing process can be significantly improved through the development of a specialized customer relationship management (CRM) [2] system. A customer relationship management system is software that helps organizations manage customer interactions and improve business processes. It allows for the collection and analysis of customer data, tracking of sales, order management, and marketing, which enhances the efficiency of the company. Such a system tracks all stages of production, from design to final processing, and integrates functionality for receiving and processing environmental photographs to adapt camouflage patterns. This enables the creation of highly accurate analytical reports on paint usage, particularly in the CMYK format, which improves the efficiency of the dyeing process and optimizes resource consumption.

Merging a DXF file with the CRM system creates a powerful tool that automates processes related to fabric dyeing and their preparation for garment production. Using the Python library ezdxf to read DXF [6] files and further integrating the read information into the process of automation and order management promotes precise control and management of all production stages. This reduces errors, shortens production time, and, as a result, lowers the cost of the product while maintaining high quality of the final product.

During fabric dyeing, the CMYK color system is used, and the paint is precisely dosed – 12 ml of paint per square meter to ensure color quality and durability. After dyeing, the materials are sent to other machines for cutting and sewing, ensuring the accuracy and speed of processing necessary to obtain a high-quality final product.

The central figure in managing this process is the CRM [2] system, which coordinates all production stages and provides recommendations for paint usage. Additionally, it plays a key role in automating the process, simplifying and optimizing workflows.

To calculate the necessary amount of paint for printing each order, it is essential to use the calculate_ink_percentage method during order creation and after receiving a response from the pattern generation service for camouflage clothing. This method analyzes the colors and their percentage ratios in the image. The method consists of several steps.

1) Opening the image and converting it into a numpy array for further processing.

2) Iterating over each part of the image and obtaining color values.

3) Determining the percentage content of each of the four CMYK colors in the image.

4) Normalizing the values so that their sum equals 100%.

5) Returning the result as a dictionary with the percentage content of each color (Cyan, Magenta, Yellow, Black).

The obtained results are used for further calculation of the required volume of each color's ink for printing, as well as for forming a report that is added to the generated PDF file of the order. This allows for an accurate determination of the amount of ink and materials needed for the production of each order, contributing to efficient management of the production process and rational use of resources.

V. DEVELOPMENT OF THE FABRIC DYEING MODULE

The developed fabric dyeing control module system is implemented using a specialized camera, which can be either stationary or portable. The choice of camera depends on the required resolution, light sensitivity, and the ability to integrate with other systems. For instance, DSLR cameras are suitable for capturing high-quality images with a large amount of detail, which is critically important for dye quality analysis.

Cameras can transmit data to the server through various interfaces, including Wi-Fi, Ethernet, or specialized computing modules like Raspberry Pi, which process the primary data before sending them (Fig. 4).

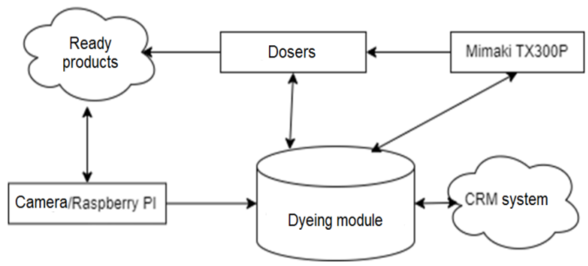

Fig. 4. Structural diagram of the dyeing control module

To enable the operation of the fabric dye analysis system, several key endpoints are proposed to be added to the existing CRM system server.

- */get-analyze-order* – this endpoint is responsible for issuing the order pattern based on a unique index. This pattern serves as a reference for comparison with the actually produced dyeing and is critically important for proper conformity analysis.
- */create-pattern* – this endpoint accepts coordinates based on the canvas in percentages, converts the received coordinates into the necessary image for printing on fabric, and generates a matrix of required CMYK system ink colors. The resulting matrix can be transmitted to dispensers, each of which will automatically accumulate the necessary amount of ink for application on the fabric based on the calculated percentages. Additionally, the obtained images can be used further in the dye quality analysis.
- */analyze* – this endpoint accepts images from the camera along with the shooting coordinates and the request name. This endpoint is used for analyzing the obtained fabric samples, comparing them with the baseline patterns, and identifying any deviations.

On the client side, an interface needs to be implemented to provide convenient access to the analysis functionality. This includes the ability to easily navigate to the appropriate analysis page with the necessary parameters. The key component should allow the user to upload images, input the necessary coordinates, and send the data to the server for analysis. The server response should display the comparison results, providing a visual representation of the analysis.

The development of such a system allows for the automation of the dye quality control process, ensuring a high level of accuracy and prompt identification of production deviations. This will contribute to improving overall product quality and optimizing production flows.

A. Development of the Backend Part of the Dye Analysis Module

For the development of the fabric dye analysis module, it is necessary to develop a class Analyze which should consist of two methods.

The core functionality of the GetAnalyzeOrder method is to obtain the order index to get the generated pattern for the dyed fabric. Using the order identifier, the method queries the database and returns the image necessary for further analysis to the client. Thanks to the integration with the database management system and the already implemented Order model, the database query is performed efficiently according to the principles of the Model-View-Controller (MVC) [1] pattern, allowing for quick data retrieval without excessive server load.

The core functionality of the CreatePattern method is that we receive the necessary coordinates and the required image of the generated pattern used in the order, split this image into percentages into different parts, and from these fixed parts, we obtain the necessary image for analysis and printing, a matrix in the CMYK [5] format. The returned image and matrix can be integrated with the Mimaki TX300P machine.

The AnalyzeImage method is designed for receiving, processing, and analyzing images. Photos received from the camera are uploaded to the server through a form, where they are temporarily stored for further processing. Additionally, the coordinates of the image obtained from the printed fabric are transmitted. These coordinates are given as a percentage of the total image size to avoid issues related to pixel size differences. Specifically, the following parameters are transmitted:

1) \`from*X*\` is the *X*-axis coordinate from which the photo was taken;

2) \`from*Y*\` is the *Y*-axis coordinate from which the photo was taken;

3) \`width\` is the width as a percentage of the total size of the dye pattern;

4) \`height\` is the height as a percentage of the total size of the dye pattern.

This approach allows for precise determination of the image area for analysis, which enhances the accuracy of fabric dye quality assessment.

The main logic of the method includes defining the coordinates of the analysis area and comparing this area with the base pattern, depending on the parameters provided by the user (percentage of the image area for analysis). All these manipulations with pixels, coordinates, and checks occur in a separate image analysis service. The analysis service, after processing the images, generates a difference image in the form of red zones on a white background, where potential errors are highlighted in red. This approach allows for quick visualization of problem areas and provides production personnel with the necessary information to correct processes if errors arise from paint, the machine, or the fabric. The analysis results are also stored in Comma-Separated Values (CSV) format, making it easy to integrate the data with other analysis systems or use them for further statistical analysis. This feature makes the system multifunctional and adaptable to the needs of modern production.

The backend development for the dye quality analysis module is done using modern technologies and programming methods, ensuring high reliability and accuracy of the analysis. Integration with advanced image processing methods and scalability allows the system to remain efficient as production volumes increase.

B. Development of the Frontend Part of the Dye Analysis Module

Let's consider the development of the frontend part of the fabric dye analysis module, which is key to automating the quality control system in the fabric dyeing process. The frontend development provides an interface through which users can interact with the system, upload images for analysis, and view the processing results.

To ensure a smooth transition to the frontend, a special link was introduced that directly directs the user to the analysis component by passing the order identifier in the already existing CRM system component List. This allows the system to automatically load the necessary parameters and order data, which is important for initiating the analysis process.

The analysis component is responsible for the main functions of the system: uploading fabric images, analyzing them, and displaying the results. The development of this component includes the use of various technical solutions, such as React [4] for developing an interactive interface, Axios for making HTTP requests to the server, and React Dropzone for implementing drag-and-drop functionality for images.

A key feature of the frontend is the ability to collect data directly from the user interface. Users can specify specific image parameters, such as coordinates (X and Y), width, and height of the image area to be analyzed. These data are used to accurately determine the area of the image where the analysis will be conducted.

After the image is uploaded to the server, the system performs a detailed analysis, comparing the dyed fabric with the original order parameters. The analysis includes identifying color and texture deviations, identifying areas with incorrect dyeing, and calculating the total number of errors as a percentage.

The frontend provides clear and informative reports on the analysis results, including visualizing errors on the image, where discrepancies are highlighted in color. Additionally, the user receives detailed information in CSV format with data on each pixel, allowing for a deeper analysis of the dye quality.

In addition to automatic analysis, the system offers the possibility of manual control, which is important for promptly addressing issues that may arise due to unforeseen circumstances. The operator can adjust the analysis parameters and resend the image for processing, ensuring maximum accuracy and control over the process.

This frontend component becomes an integral part of the dye quality automation system, allowing not only the automation of the analysis process but also providing high flexibility and compliance with production standards.

C. Development of the Fabric Dye Analysis and Dyeing Module

For the development of the dye analysis module, it is first necessary to create a method that will analyze the image of the camouflage pattern to be printed. This method should not only identify color deviations but also form a CMYK matrix, which will be used for correction and printing on the Mimaki TX300P textile machine. After this, we need to create a service that will send HTTP requests to the machine to implement printing.

The calculate_cmyk_matrix method opens the image by the specified path, converts it into a pixel array, and then calculates the CMYK[5] values for each pixel. The calculated values are stored in a three-dimensional array. After that, the method writes the obtained data to a CSV file, saving the coordinates of each pixel along with the corresponding CMYK values.

1) Opening the Image: The method starts by opening the image using the PIL library. This allows the image to be loaded in a format suitable for further processing.

2) Converting to a numpy Array: The image is converted into a numpy array for ease of processing. The array allows easy access to the values of each pixel.

3) Initializing the CMYK Matrix: A zero matrix is created, having the same dimensions as the image, with four channels for CMYK values.

4) Calculating CMYK Values: By iterating over each pixel, the method calculates CMYK values based on the RGB values. These values are normalized so that their sum equals 100%.

5) Saving the Matrix to a CSV File: The resulting matrix is saved in a CSV file, where each row contains the pixel coordinates and corresponding CMYK values.

After obtaining the color matrix, it is necessary to create a service that will send HTTP requests to the Mimaki TX300P printer for printing implementation. The send_cmyk_data function reads data from a CSV file containing the CMYK matrix and sends it to the printer's API [3]. If the request is successful, a message indicating successful data transmission is displayed; in case of an error, the corresponding status code is displayed.

The principle of its operation.

1) Reading the CSV file: The service starts by reading the CSV file containing the CMYK matrix.

2) Sending data: Data from the CSV file is sent to the printer via an HTTP POST request. The printer's API URL is determined in advance.

3) Processing the response: After sending the data, the service processes the response from the printer, checking the success of the operation.

D. Development of a Fabric Painting Analysis System

For the final development of the fabric painting analysis module and the generated fabric in the order, a service was created to compare images of painted fabric obtained from the camera with data reflecting the planned result. Through the analysis, it is possible to identify errors and visualize them for correction of the production process.

The fabric painting quality analysis service is designed to ensure the accuracy of reproducing the planned patterns on the fabric. It is intended to detect discrepancies between the actually painted fabric and the digital image that served as the template. This allows for timely detection of errors and corrective actions, reducing the percentage of defects and optimizing paint consumption.

The PNGManager class is initiated to manage the images involved in the analysis process. After initialization with the mandatory parameter – the path to the image, temporary directories are created for storing processed image fragments.

The split_image method divides the main image into 100x100 parts, allowing detailed analysis of each segment. This is especially useful for detecting localized defects. Each segment is stored separately, ensuring its further use in comparative analysis.

The combine_images method is used to synthesize image parts back into a whole. This allows visually verifying the analysis results in real conditions, providing the opportunity to compare before and after processing.

The core functionality of the system is implemented in the compare_images method. This method performs pixel-by-pixel comparison between the base image (generated by the order) and the analyzed image (actually painted fabric). It generates a visual image of errors, marking discrepancies in red, and produces two types of CSV files: one with detailed data for each pixel and another in the form of a matrix showing summarized information. This ensures in-depth analysis and the ability to adjust processes based on the obtained data.

VI. Conclusion

The creation of camouflage uniforms is crucial for both military and civilian applications, particularly in survival and hunting. Camouflage clothing enables individuals to blend into their surroundings, enhancing safety and efficiency in forested environments where predators may be present. For hunters, it allows close approaches to wild animals without detection. Effective camouflage requires precise reproduction of colors, textures, and patterns, increasing success in hunting and unnoticed movement. Therefore, developing camouflage uniforms ensures maximum adaptation to local terrain.

The fabric dyeing process is key to producing high-quality camouflage uniforms. It includes fabric preparation, dyeing, and stringent quality control to achieve the desired coloration and properties. Fabric preparation involves cleaning to ensure uniform dye absorption. Processes like soaking, bleaching, and mercerization improve dye absorption and color durability.

Dyeing methods vary by fabric type and desired effect. Natural fibers like cotton are dyed with reactive dyes for bright, durable colors, while synthetics like polyester use disperse dyes that form thermal bonds. Quality control includes visual inspections and tests for colorfastness under light, abrasion, sweat, and water, ensuring high standards and consumer satisfaction.

Advanced dyeing methods like continuous dyeing, spray dyeing, stencil dyeing, and digital printing offer specific benefits. Continuous dyeing is efficient for large batches, spray dyeing allows precise dye application, stencil dyeing creates detailed patterns, and digital printing provides photorealistic results. Machines like the Mimaki TX300P handle various fabric widths with high precision and reliability, enhancing consistency and efficiency.

Automating the dyeing process with machines like the Mimaki TX300P improves efficiency and quality. These machines support high-speed printing and advanced ink technology, optimizing ink consumption and streamlining production with integrated fabric loading, printing, and cutting systems.

A customer relationship management system further automates garment creation, enhancing design, order management, and quality control. Tools like CLO3D enable detailed 3D modeling and accurate pattern reproduction. The CRM system coordinates all production stages and provides precise paint usage recommendations, ensuring efficient resource management and high-quality outcomes.

In conclusion, developing and automating fabric dyeing processes for camouflage uniforms involves advanced technologies and quality control. Integrating digital printing machines, CRM systems, and software like CLO3D enhances production efficiency and precision, ensuring durable, colorfast camouflage clothing that blends effectively into natural environments for civilian and military use.

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В. М. Синєглазов, М. О. Башенко. Автоматизоване проектування камуфляжу на основі штучного інтелекту

У статті обговорено розробку системи виробництва камуфляжної форми для цивільного використання з акцентом на виживання та полювання. Ефективний камуфляж вимагає точного відтворення кольорів, текстур і візерунків конкретних ландшафтів, що підвищує успіх полювання та непомічений рух. Розглянуто технологічний процес фарбування тканини, необхідний для виготовлення якісної камуфляжної форми, включає підготовку тканини, фарбування та суворий контроль якості. Підготовка тканини включає очищення, замочування, відбілювання та мерсеризацію для забезпечення рівномірного вбирання барвника та довговічності. Методи фарбування залежать від типу тканини: для натуральних волокон використовують реактивні барвники, а для синтетичних – дисперсні. Контроль якості включає візуальні перевірки та випробування на стійкість кольору за різних умов. Проаналізовано передові методи фарбування, такі як безперервне фарбування, фарбування розпиленням, фарбування за трафаретом і цифровий друк, пропонують певні переваги. Такі машини, як Mimaki TX300P, обробляють тканину різної ширини з високою точністю та надійністю, підвищуючи ефективність. Автоматизація за допомогою Mimaki TX300P спрощує процес фарбування, оптимізуючи споживання чорнила та інтегруючи системи завантаження тканини, друку та різання. Система управління взаємовідносинами з клієнтами додатково автоматизує створення одягу, покращуючи дизайн, керування замовленнями та контроль якості. Такі інструменти, як CLO3D, забезпечують детальне 3D-моделювання та точне відтворення шаблонів. Система управління взаємовідносинами з клієнтами координує етапи виробництва та надає точні рекомендації щодо використання фарби, забезпечуючи ефективне управління ресурсами та високу якість результатів.

Ключові слова: технологічний процес фарбування тканини; генеративно-конкурентний мережевий камуфляж; управління взаємовідносинами з клієнтами; штучний інтелект; автоматизоване проектування; контроль якості.

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Напрям наукової діяльності: аеронавігація, управління повітряним рухом, ідентифікація складних систем, вітроенергетичні установки, штучний інтелект.
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