VR simulator for the training and manufacturing process at sewing enterprises*

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Abstract

The creation of a VR simulator for the training and manufacturing process at sewing enterprises is a relevant area that contributes to improving the quality of training and the competitiveness of enterprises in the labor market. This study is aimed at designing and developing a VR simulator for the training and manufacturing process at sewing enterprises, in particular, designing and developing a VR simulation of the structure of a sewing machine with realistic 3D modeling and accurate programming of the kinematics of its mechanisms. The designed VR simulator for the training and manufacturing process at sewing enterprises ensures an increase in the efficiency of professional training of specialists in the sewing industry (sewing production technologists, mechanics, and masters of sewing products), by automating (for the sake of simplicity and safety) the process of studying complex structures through the conversion of technical 2D drawings into a high-precision 3D model, ready for interactive interaction in a VR environment. The proposed VR simulator automates (for the purpose of simplification and visualization) the process of studying the complex technical structure of a sewing machine, allowing skills to be practiced in a virtual 3D model on a 1:1 scale, and also forms the basis for objective testing and assessment of the knowledge gained without the risk of damaging real equipment. The developed VR simulator is an innovative, immersive, and cost-effective information product that transforms traditional technical drawings into an interactive space for in-depth study of the design and operating principles of a sewing machine, providing high-quality training for specialists in the sewing industry and mechanical engineering.

Keywords

Virtual reality (VR), VR simulator, 3D modeling, sewing machine structure, interactive simulation.[1]

1. Introduction

Light industry, and in particular the sewing industry, is an important component of Ukraine's economy. In 2021, the volume of sales of textile, clothing, and leather products amounted to over UAH 29 billion. The sewing industry is one of the sectors of light industry that is developing dynamically and requires highly qualified specialists capable of working effectively in conditions of rapid technological change. In the current context of digitalization of production, the sewing industry is increasingly integrating intelligent control systems, robotic complexes, and automated assembly lines [1, 2]. Modern production is based on the use of automated equipment, computer-aided design (CAD/CAM) systems, and digital management technologies. Such technological solutions ensure high precision, reduced production costs, and increased labor productivity [3].

Despite its dynamic development, the sewing industry faces a significant shortage of personnel. The low attractiveness of the profession among young people, as well as the gap between

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traditional vocational education and the needs of modern production, complicate the training of the necessary number of qualified personnel [4, 5].

At the same time, the digital transition in sewing factories necessitates the training of specialists who not only possess traditional technological skills but also have competencies in IT, automation, and production process analytics. In other words, the digital transition requires employees to have not only professional skills and manual labor skills but also an understanding of the principles of innovative technological processes. In general, further automation of production is expected worldwide by 2030, which will require workers to have not only sewing skills but also a deep understanding of how complex equipment works [6].

Modern sewing factory workers must understand the principles of computerized machine control systems, be able to work with digital product models, optimize technological operations using software, and quickly adapt to new technical solutions. The level of these competencies determines the efficiency of production, the quality of finished products, and the ability of the enterprise to compete in the global market [7-9].

Therefore, one of the key tasks of educational institutions is to modernize the educational process through the introduction of digital and virtual technologies that reproduce the conditions of modern production. This allows us to train a new generation of specialists who are versatile, technologically literate, and ready to work in the conditions of Industry 4.0 [10]. Currently, a digital educational space is being created around the world, which consists of the development of simulators and virtual trainers, the release of interactive 3D manuals, and the use of augmented (AR) and virtual (VR) reality for training specialists.

At the same time, the vocational training system in many educational institutions faces a number of challenges, such as limited access to modern production equipment and high costs of training materials. In such conditions, traditional teaching methods do not always allow for the full development of the necessary competencies of future specialists in the sewing industry [11, 12].

The use of virtual reality (VR) in the educational and production process opens up new opportunities for solving these problems [13]. In conditions of complete immersion, the human brain is able to assimilate complex spatial and mechanical information more quickly, so virtual simulators created using 3D modeling and VR interaction technologies will allow students to “see” the workings of internal components of a mechanism (e.g., a sewing machine) and disassemble and reassemble it in a safe environment. Accurate simulation of the physics of objects and step-by-step equipment maintenance scenarios when creating a VR simulator can effectively and intuitively convey practical skills that are not available when studying flat diagrams.

VR simulators provide modeling of real production situations, allow you to practice technological operations in a safe environment without wasting material resources, which contributes to the formation of professional skills, the development of spatial thinking, and increased motivation to learn. VR simulators provide a standardized approach to practicing key operations (from threading an overlock machine (edge binding machine) to programming automatic machines), ensuring that each trainee receives the same high-quality practical experience. VR simulators reduce the adaptation period for new employees by 30-50% and minimize material costs, allow skills to be practiced to a high level without the risk of damaging raw materials, and enable employees to be safely trained in complex and potentially dangerous operations that can be expensive to repeat or carry a high risk of injury in real production. Gamification elements in the VR environment increase the motivation of applicants and make the learning process more attractive to the younger generation. Virtual reality and augmented reality (AR) technologies allow you to create a realistic, highly detailed environment that perfectly simulates the operation of modern industrial sewing equipment. The VR simulator allows you to conduct training remotely, regardless of the physical location of the equipment, which is especially relevant in today's conditions. Thanks to VR simulators, companies can ensure continuous professional development of their employees and rapid retraining of personnel during the introduction of new technologies or changes in the product range, which is critical for production flexibility in a competitive market environment. Thus, the introduction of VR simulators is in line with current trends in the digital transformation of education, the principles of Industry 4.0, and the concept of Smart Manufacturing, ensuring a closer connection between the educational process and the real needs of sewing manufacturers [14-16].

That is why the development of a VR simulator for the training and production process of garment factories is not just an innovation, but a strategic necessity to ensure the competitiveness of the entire light industry of Ukraine [17]. So, the creation of a VR simulator for the training and manufacturing process at sewing enterprises is *a relevant area* that contributes to improving the quality of training and the competitiveness of enterprises in the labor market..

2. Literature review

Let's conduct a survey of known methods and tools for using VR simulators in the training and manufacturing process in industry.

A study [18] dedicated to a virtual training system for horizontal directional drilling rigs offers a design scheme based on Unity3D to overcome equipment shortages and hidden dangers in traditional training. The program uses model building in Solidworks and 3dsMax, virtual animation development in Unity3D, 3D trajectory algorithm output based on the Rodriguez rotation matrix, and software and hardware communication through data collection. Experiments have proven that the system is viable, demonstrates good controllability and true immersion, and is more convenient, cheaper, and safer than traditional methods, which increases the effectiveness of training.

Article [19] addresses the problem of training oil depot personnel, where traditional systems have a theoretical bias. The authors develop an interactive virtual training system for oil depots on the Unity3D platform, using C# as the language for interactive scripts and SQL Server for data management. The system implements the functions of equipment attribute queries, interactive control, and simulation of important technological processes in the form of first-person roaming. It is claimed that the system has a very realistic three-dimensional effect and interaction function, which enhances the training effect.

A study [20] on teaching high school students programming through video game development confirmed that game development provides high motivation and engagement. The authors used the Unity Game Development Environment, a professional tool with a built-in physics engine. The results of the first iteration confirmed the hypothesis about the engaging nature of the process. The key conclusions were that the successful use of professional tools in secondary education requires a systematic approach to the complexity of the environment, effective time management, and high teacher competence.

The main goal of the proposed project [21] was to improve the quality of teaching for technical program specialists (Applied and Automotive Mechatronics) by using the latest ICT, virtual and mixed reality to visualize modeling and control processes of complex mechatronic systems. It is expected that visualization will give students a better understanding of the material being studied compared to conventional methods.

Project [22], prompted by the COVID-19 pandemic, focused on developing an immersive virtual reality application as a training method for interacting with a vertical milling machine. The project used Solidworks and Blender software to configure the machine assembly, as well as Unity to develop the VR application. This system allows users to recognize the parts and functions of the machine and simulate real interactions, which can be implemented in various educational institutions for dynamic teaching of mechanical engineering.

Article [23] explores the issue of intensive training of machine operators to prevent equipment damage. The authors compared the effectiveness of training using a virtual full-size simulator with real walking and traditional instructions on a real machine. The results of an objective assessment (task completion time and number of errors) conducted a week later showed that the group trained virtually slightly outperformed the group trained in reality. This confirms the potential of virtual models for learning basic operating principles.

Paper [24], devoted to the development of a networked virtual environment using VR headsets for industrial applications, notes that current VR applications for industry often have limited interaction and teamwork capabilities. The virtual environment is a simplified copy of a real factory and supports up to 20 users connected via the Internet. The developed system allows users to see and hear each other, as well as interact with objects that require joint participation. Simplified instructions and interaction capabilities with a lathe were developed.

Research [25] aims to design an innovation in virtual simulation training based on augmented reality in the form of a sawing machine to improve the special skills of vocational school students during the COVID-19 pandemic. The research uses a development and refinement method that includes design, product testing, and expert evaluation. Among the key conclusions is that the developed innovation is viable and effective in improving the special skills of students.

The aim of the thesis [26] is to develop and implement a construction training simulation using Unity software. The objective was to create an interactive and immersive learning environment for learning construction skills in a virtual world. The thesis describes in detail the process of creating an effective VR application, including coverage of the main tools such as the Unity engine and Blender software. The result is a fully functional VR simulation that has been proven by company feedback to have the potential to increase training efficiency, reduce costs and improve safety measures in the construction industry.

The paper [27] analyzes the effectiveness of virtual safety training using VR helmets compared to flat screens among novice tower crane operators. The study found that VR headsets increase efficiency due to greater immersion, realism and depth perception, increasing the accuracy of identifying critical hazards such as electrical cables.

The paper [28] is devoted to the application of VR technologies to create virtual training simulations for assembly or maintenance tasks in industry. The authors propose a structured methodology to create an interactive virtual space where operators can perform tasks in a realistic way while receiving specialized instructions (learn-by-doing). The methodology was successfully applied to an industrial case study concerning the assembly phases of a tractor and confirmed that the new learning process is faster and more intuitive.

Research [29] explores the benefits of using Virtual Reality (VR) to visualize architectural models with increased detail compared to traditional drawings. The use of the Unity engine allows multiple architects and clients to seamlessly collaborate on a detailed VR model of a building, while VR technology allows for immediate identification and correction of errors. This highlights the significant benefits of VR in modern architectural practice.

Existing simulators of the training and manufacturing process of sewing enterprises are very limited, although there are some attempts to introduce applicants to digital technologies. For example, some companies offer 2D simulators of the sewing process, where the student learns to sew a straight line on a computer screen [30]. There are also video tutorials [31, 32] and 3D animations on YouTube [33] that demonstrate the operation of a sewing machine. However, these solutions are not interactive. A student cannot "take" a virtual unit, "disassemble" the mechanism, and see the consequences of his actions in real time.

So, currently in Ukraine and in the world as a whole, VR simulators for the training and manufacturing process of sewing enterprises, in particular, VR simulations of the structure of a sewing machine, are practically unavailable, although the wider use of an immersive approach makes technical education safe and accessible to everyone.

Therefore, *this study is aimed* at designing and developing a VR simulator for the training and manufacturing process at sewing enterprises, in particular, designing and developing a VR simulation of the structure of a sewing machine with realistic 3D modeling and accurate programming of the kinematics of its mechanisms..

3. VR simulator for the training and manufacturing process at sewing enterprises

Let's design a VR simulator for the training and manufacturing process at sewing enterprises, in particular, let's create a VR environment in which you can safely and in detail familiarize yourself with the functioning and structure of a sewing machine.

The main source of information, and accordingly the primary information, in the virtual simulator are the technical drawings of the sewing machine, as well as text descriptions and instructions for its operation. To implement this idea, the Blender software was used, in which the simplest sewing machine was modeled and built, in which the main mechanisms involved in its operation were implemented. After all the necessary components were modeled, these parts were exported to the Unity 3D game engine for further assembly of a functional model with a brief description of the parts. In the Unity 3D game engine, the ability was implemented for the main components of the sewing machine to be grabble for the user, that is, so that the user could virtually "take" them, estimate their size and examine them from all sides. Also, each functional mechanism was assigned a digital number that corresponded to a brief description of the part and the principle of operation of this part, so that the user could familiarize himself with the purpose of such a part.

Using the software from Meta Quest, the developed VR simulator was loaded into the Meta Quest 3 VR glasses, which made it possible to conveniently launch this simulator. The software from Meta Quest also allows you to track and control the version of this simulator to make changes depending on the version. So, the received technical information is processed — 3D modeling is performed in Blender, segmentation into separate interactive parts, mesh optimization, as well as programming of kinematics and interaction in Unity, as a result of which an information product is formed — a VR application, which is an interactive 3D model ready for use on the Meta Quest headset. In parallel, information is collected from the instructions regarding the names and functions of the parts. An additional information product is being formed — interactive captions and short descriptions of virtual parts, which are displayed in Unity during interaction. This provides feedback to the applicant and the possibility of automatic testing of his knowledge in a virtual environment. The process of creating a VR simulator for the training and manufacturing process at sewing enterprises is presented in Fig. 1. The designed VR simulator for the training and manufacturing process at sewing enterprises ensures an increase in the efficiency of professional training of specialists in the sewing industry (sewing production technologists, mechanics, and masters of sewing products), by automating (for the sake of simplicity and safety) the process of studying complex structures through the conversion of technical 2D drawings into a high-precision 3D model, ready for interactive interaction in a VR environment. The proposed VR simulator automates (for the purpose of simplification and visualization) the process of studying the complex technical structure of a sewing machine, allowing skills to be practiced in a virtual 3D model on a 1:1 scale, and also forms the basis for objective testing and assessment of the knowledge gained without the risk of damaging real equipment.

4. Results & discussion

The designed VR simulator for the training and manufacturing process of sewing enterprises, in particular, for the professional training of specialists in the sewing industry and understanding the principle of operation of the main functional parts of a sewing machine, was implemented.

Fig. 2 shows the numbering of functional parts with a brief description (in Ukrainian, because this simulator is designed primarily for Ukrainian sewing enterprises) of their functioning and role in the operation of the sewing machine. Fig. 3 shows a part that is interactive and has an individual number tied to the description of the functional unit for understanding the principle of operation of this unit. Fig. 4 shows two different functional units with individual numbering tied to the description of these units.

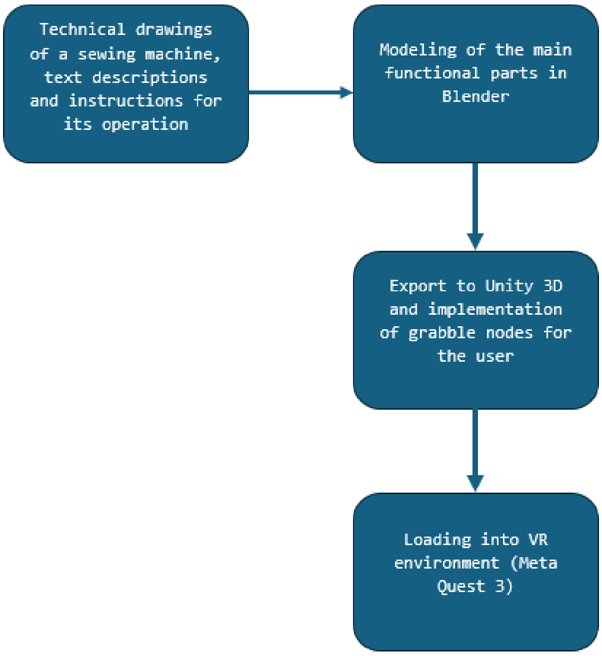

Figure 1: The process of creating a VR simulator for the training and manufacturing process at sewing enterprises.

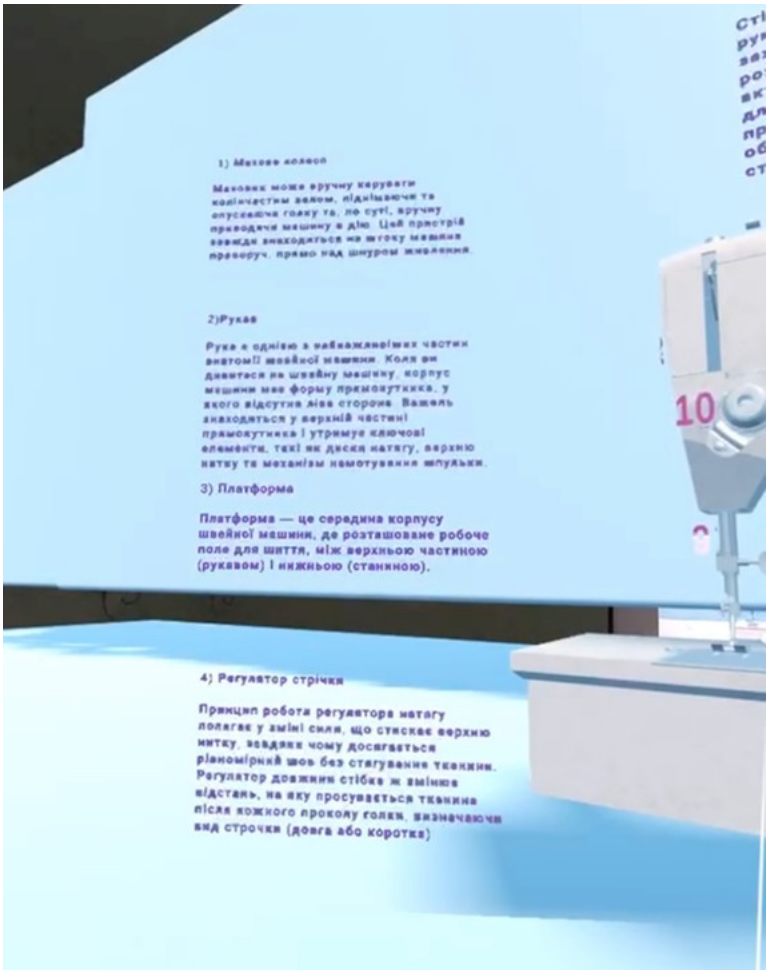

Figure 2: Brief description (in Ukrainian) of the main functional parts with numbering.

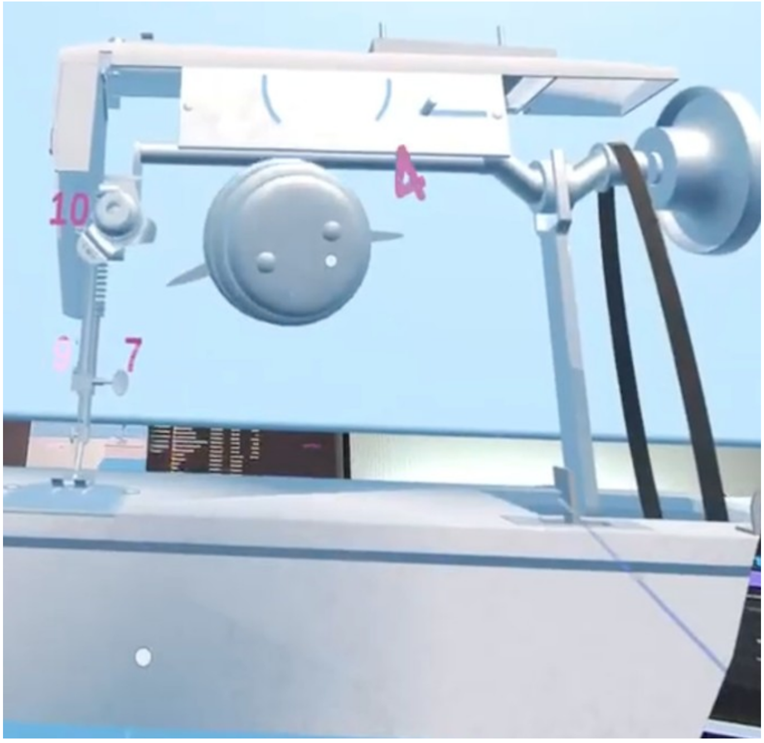

Figure 3: Demonstration of an interactive detail with numbering attached to the description of functional details.

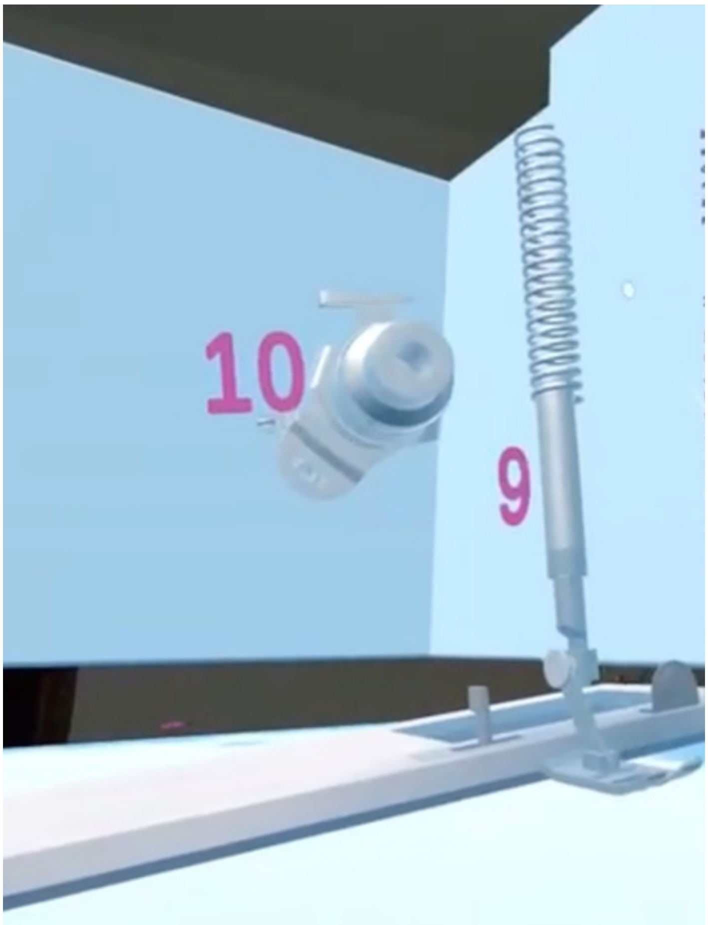

Figure 4: Functional components of a sewing machine with individual numbering.

So, thanks to 3D modeling in Blender, the user can see and understand the operation of the internal mechanisms of a sewing machine (for example, a shuttle mechanism), which are hidden on real equipment. This allows you to form a deep engineering understanding, and not just a motor skill. The ability to virtually "grab" individual functional units and examine them from all sides allows you to feel their size and shape, which is critical for the assimilation of technical knowledge.

The use of the powerful Meta Quest 3 platform provides high quality graphics and a realistic immersion experience. The ability to track and control the version of the simulator (via the Meta Quest software) allows you to quickly make changes and upgrade the functionality (for example, add new machine models or task modules) centrally.

Assigning digital numbers and short descriptions to functional mechanisms provides feedback to the learner directly in the virtual environment. This turns dry technical drawings and instructions into an interactive, context-sensitive training manual. The user does not just see the part, but immediately learns its name, function and principle of operation, which accelerates the formation of professional terminology.

Training takes place without the use of real expensive equipment and materials. This completely eliminates the risk of a sewing machine breakdown by an inexperienced user and minimizes the cost of raw materials (fabric, thread).

The user can practice complex operations, assemble and disassemble mechanisms an unlimited number of times until they achieve perfection, without time or resource restrictions. Segmentation into interactive parts and the presence of descriptions lays the foundation for automatic knowledge testing, which increases the objectivity of the assessment.

So, the developed VR simulator is an innovative, immersive, and cost-effective information product that transforms traditional technical drawings into an interactive space for in-depth study of the design and operating principles of a sewing machine, providing high-quality training for specialists in the sewing industry and mechanical engineering.

5. Conclusions

The creation of a VR simulator for the training and manufacturing process at sewing enterprises is a relevant area that contributes to improving the quality of training and the competitiveness of enterprises in the labor market.

This study is aimed at designing and developing a VR simulator for the training and manufacturing process at sewing enterprises, in particular, designing and developing a VR simulation of the structure of a sewing machine with realistic 3D modeling and accurate programming of the kinematics of its mechanisms.

The designed VR simulator for the training and manufacturing process at sewing enterprises ensures an increase in the efficiency of professional training of specialists in the sewing industry (sewing production technologists, mechanics, and masters of sewing products), by automating (for the sake of simplicity and safety) the process of studying complex structures through the conversion of technical 2D drawings into a high-precision 3D model, ready for interactive interaction in a VR environment.

The proposed VR simulator automates (for the purpose of simplification and visualization) the process of studying the complex technical structure of a sewing machine, allowing skills to be practiced in a virtual 3D model on a 1:1 scale, and also forms the basis for objective testing and assessment of the knowledge gained without the risk of damaging real equipment.

The developed VR simulator is an innovative, immersive, and cost-effective information product that transforms traditional technical drawings into an interactive space for in-depth study of the design and operating principles of a sewing machine, providing high-quality training for specialists in the sewing industry and mechanical engineering.

Further research should focus on expanding the functionality of the proposed VR simulator in three key areas: practical skills training, fault diagnosis, and learning effectiveness analysis.

For example, the implementation of a simulation of threading a sewing machine (including winding the bobbin and installing the bobbin cap), adjusting thread tension (with a visual demonstration of the consequences of incorrect settings), as well as practicing sewing operations (feeding the fabric under the presser foot, emphasizing the necessary speed and coordination of the hands to obtain an even seam) will transform the trainer into a full-fledged simulator of manual labor.

Programming of the most common malfunctions (e.g., thread breakage, skipped stitches, poor looping, jamming), virtual user diagnosis algorithm (check the needle, thread, tension, shuttle), as well as the implementation of virtual repair capabilities (needle replacement, cleaning the shuttle mechanism from lint, lubrication) are critical for training specialists capable of maintaining continuity of production.

The introduction of accurate metrics for quantitative assessment of task performance (execution time, number of errors, accuracy of movements, correctness of diagnostics), expansion of the current database of descriptions into a full-fledged interactive library with technical specifications and instructions in PDF format and 3D models of various types of sewing machines (sergers (overlock machines), flat-seam machines, semi-automatic machines for sewing buttons and looping), as well as allowing the teacher or master to connect to the applicant's VR session of the applicant for remote monitoring, providing tips and demonstrating the correct actions in real time will transform the simulator into a centralized educational hub, providing applicants with a comprehensive understanding of various industrial equipment and immediate access to all necessary technical documentation in an interactive VR environment.

Declaration on Generative AI

During the preparation of this work, the authors used Grammarly in order to: grammar and spelling check; DeepL Translate in order to: some phrases translation into English. After using these tools/services, the authors reviewed and edited the content as needed and take full responsibility for the publication’s content.

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