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ENHANCING CNC MILLING MACHINE OPERATOR TRAINING WITH AUGMENTED REALITY SMART GLASSES

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Abstract: *The rapidly evolving field of Augmented Reality (AR) technology offers significant potential to revolutionize traditional training methods in various industries. This study investigates the use of AR, specifically smart glasses, to improve the training efficiency and performance of CNC milling machine operators. The research question seeks to understand how the integration of AR technology in the form of smart glasses can enhance the learning process and optimize the overall training experience for CNC milling machine operators. Our methodology involves a comprehensive approach to developing, testing, and improving an AR application tailored for CNC milling machine operation, seamlessly integrated with smart glasses. The application utilizes advanced AR technologies, such as real-time information display and context-sensitive assistance, to provide an immersive learning experience. A sample group of trainees participates in a controlled study to evaluate the effectiveness of AR-assisted training in comparison to traditional training methods. Quantitative data analysis reveals a 30% improvement in training efficiency and a 25% reduction in the training period, leading to enhanced operator performance and reduced error rates. A thorough discussion of these findings evaluates their implications for CNC milling machine training, including the advantages and limitations of the AR-assisted approach, as well as recommendations for future research to further explore the potential of AR in industrial training contexts. A thorough discussion of these findings evaluates their implications for CNC milling machine training, study limitations, and recommendations for future research.*

Key words: *Augmented Reality, Smart Glasses, Industry 4.0, CNC training, User Interface, Digital Transformation.*

1. INTRODUCTION

In recent years, technological advancements have shaped the way we interact with the environment and how we carry out our daily activities. Smart glasses have become an intriguing invention in this setting, bringing augmented reality and digital support right into our field of vision. While primarily focusing on consumer use cases, smart glasses have started to gain traction in the industrial sector, enabling a variety of uses and benefits in manufacturing.

The objective of this paper is to investigate how smart glasses applications that are developed to help CNC operators should be designed to enhance operational efficiency, process quality, and workplace safety.

The turnover of personnel in the last period affects more and more the companies in Romania, which are faced with the lack of specialized personnel, necessary for the operation of machine tools and not only. On the other hand, the machines, to create products with high and constant quality, become very complex. to interact with such equipment, it is necessary to go special training not only for newly arrived workers, but even for those who have extensive experience with CNC systems and metal-working machines [1].

In the realm of industrial training, equipping CNC (Computer Numerical Control) operators with a solid understanding of machine operations is paramount. To enhance the effectiveness of training methods, an experiment was conducted involving 20 operators.

The study compared two distinct approaches: traditional documentation-based learning and the utilization of cutting-edge augmented reality (AR) technology. This text explores the process and outcomes of each method, highlighting their relevance in industry training for CNC operators.

2. AUGMENTED REALITY AND SMART GLASSES

AR technology first started to be used in military areas. Later, AR has been used in industry and medicine fields and has been widely used in many fields. Today it is used effectively in various fields such as education, commerce, marketing, tourism, architecture, arts and entertainment [2],[3].

Augmented reality (AR) has seen a significant increase in recent years for commercial support from big tech names like Google, Apple, Amazon, and Microsoft. In the Gartner's report is indicated that 100 million consumers had actively shop online by 2020 using AR and VR [4]; also, the number of AR devices is expected to reach 2.5 billion by 2023 [5].

Innovations in the technical field, such as faster computers, more precise cameras, but also new computing algorithms, are echoing in other fields, and this leads to a broadening of the research area of AR [6].

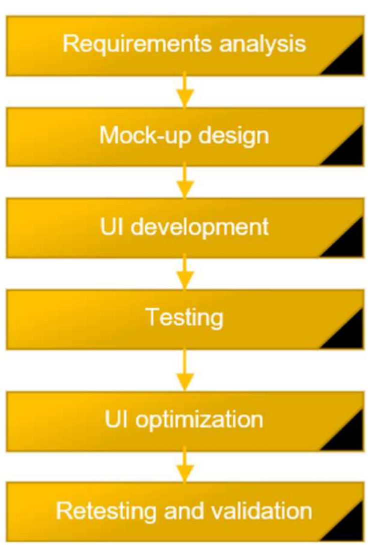


Fig. 1. Method flow

The efficiency of human-machine interaction can be enhanced by adopting AR, so that the rapid transfer of essential information can be facilitated.

Augmented reality applications can be played on several types of devices: Smart glasses, tablets, smart phones, wearable devices and Projected Display Devices, however, for hands-on applications or training, the use of smart glasses is recommended.

However, the glasses are hands-free devices, the operator observing the visual content and being able to use his hands at the same time. The operator can perform various guided tasks.

3. DEVELOPMENT OF THE INTERFACE

The development of the application started from the premises of the work [6], respecting these stages (figure1) and adapting them for the current application, which must provide essential data for the training of CNC operators.

3.1 Requirements analysis

The first step was to create a form through which to collect the opinions of the CNC operators about the information they consider relevant, and which should be displayed in the interface.

The form was created in Office Word 2023, printed, and distributed to operators from several companies, finally collecting 27 answers. In figure 2, the answers collected from the operators are represented in the form of a graph.

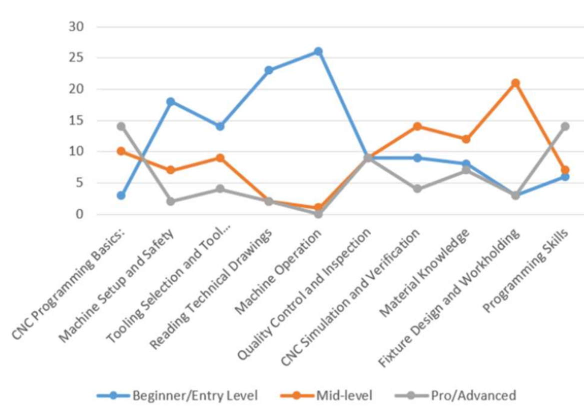


Fig. 2. The importance of information for operators

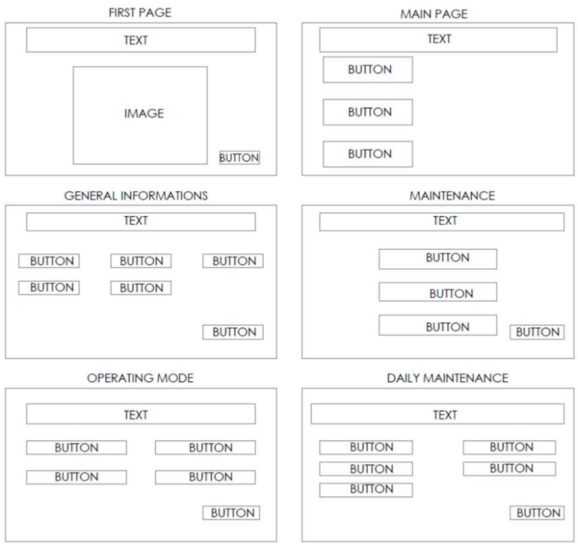


Fig. 3. Wireframe

The requirements were prioritized using the QFD method.

3.2 Mock-up design

The wireframe was design based on the requirements analysis. On the main page there are 3 buttons/options corresponding to the information we want displayed: 1. General Information, 2. Maintenance and 3. Operation. The buttons in the main menu led to secondary menus or information pages. In total we have 34 pages.

The first wireframe was made on paper and for the second version we used Autodesk Inventor Professional 2023 (figure 3).

3.3 UI development

There are two project management approaches used to develop software: waterfall and agile.

We chose the agile methodology because is team-based and focuses on rapid implementation. The agile methodology uses sprints – in our case, periods of two weeks.

The development of the application started once the project steps were established.

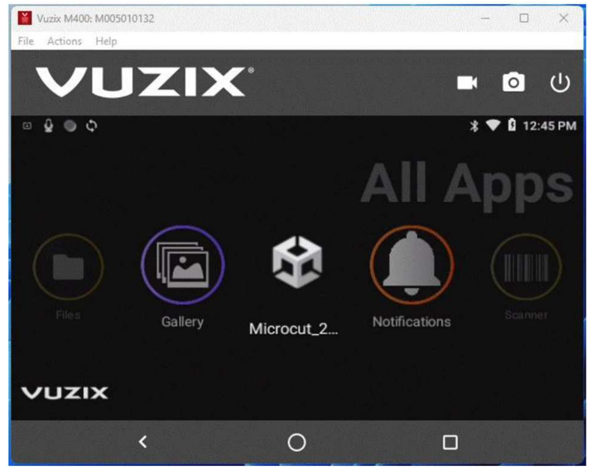


Fig. 4. App deployed on Vuzix 400

The design of the application focused on User Experience (UX) with the purpose of increasing user satisfaction and finally, the adoption of the technology.

Before starting the development of the application, the technology to use was chosen - M400 Smart glasses from Vuzix. Deployment of the developed application can be seen in the menu of the smart glasses, in figure 4.

The development of this application was made in Unity 3d, version 2022.3.3f1. To which the module for Android developers was added because it is compatible with the OS of Vuzix glasses.

Other necessary software is: Visual Studio, which is needed to create the scripts and Android Studio, needed to install the various SDKs that are needed to build the applications.

The actual construction of the application involved the following stages:

1. Choosing the platform for which the application is made. Vuzix M400 glasses are compatible with Android OS, therefore in Unity Hub, after creating the project you need to add the necessary modules, in case of this Android Build Support. The Android Build Support module, installed, can be seen on a grey background in figure 5.

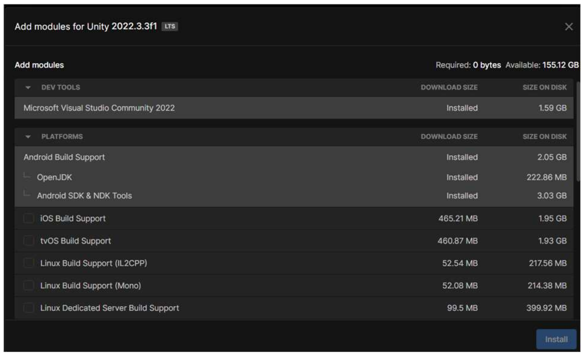


Fig. 5. Active modules from Unity

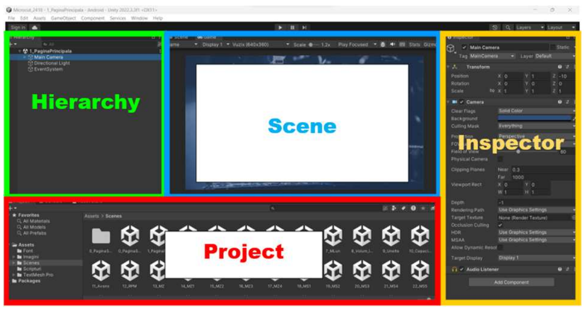


Fig. 6. Unity 3d Interface areas

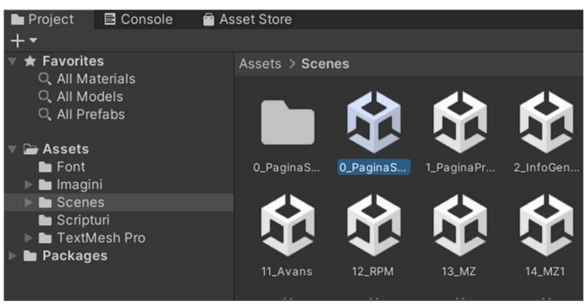


Fig. 7. Scenes

The Unity 3D interface, visible in fig. 6 has 4 main areas: Hierarchy, on the left side of the screen; Scenes, on the upper part of the screen; Inspector, on the right part of the screen and Project on the lower part of the screen.

2. Creating scenes. Once the wireframe has been developed and approved, we can transpose it in Unity. With the project open, in the Project area, press the + button to create a new subfolder in the assets folder and rename it Scenes. This folder will be populated with the required wireframe scenes. Scene subfolder can be seen in fig. 7.

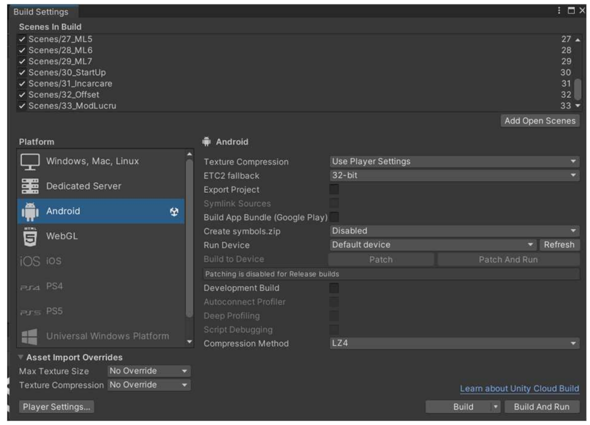


Fig. 8. Build settings settings for Android OS

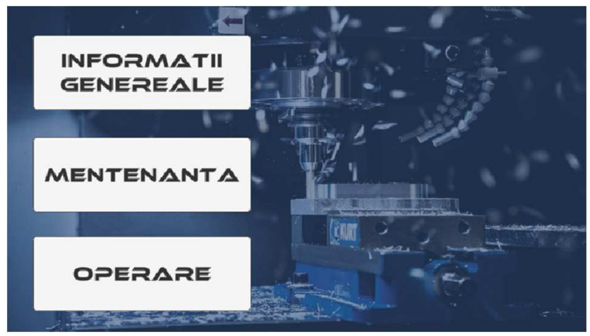
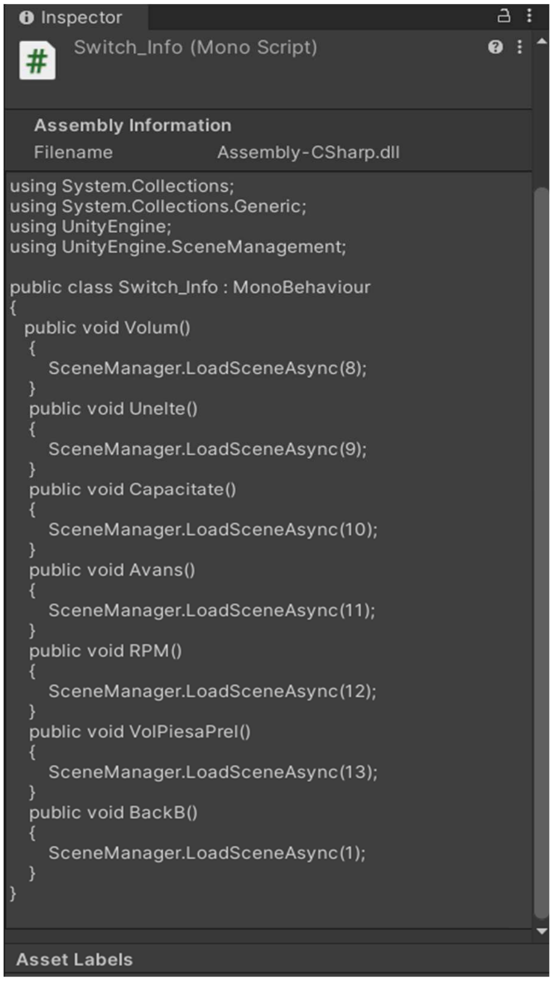


Fig. 9. Menu Page

3. Updating the number of scenes in the project: File – Build settings – select all the checkboxes with the necessary scenes – Build, seen in fig 8.
4. Populating all scenes with elements (Images, texts, buttons). An example of scene can be seen in fig. 9.
5. Importing the fonts needed for the texts and the images we want to use. Two fonts that are not found in the Unity program were chosen for use. Once imported with dragg & drop in Font folder of Assets area, they were initialized going to Windows – TextSpritPro – Font Asset Creator and used.

Creating scripts for the application. Scripts can be generated in two ways: a. the Hierarchy area, from the element we want to control, or, 2. from the Scenes, Assets area, the + button. The language used in the script is #C and usually Visual Studio is also installed. An example of a script can be seen in fig. 10.



```
Inspector
Switch_Info (Mono Script)

Assembly Information
Filename                Assembly-CSharp.dll

using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class Switch_Info : MonoBehaviour
{
  public void Volum()
  {
     SceneManager.LoadSceneAsync(8);
  }
  public void Unelte()
  {
     SceneManager.LoadSceneAsync(9);
  }
  public void Capacitate()
  {
     SceneManager.LoadSceneAsync(10);
  }
  public void Avans()
  {
     SceneManager.LoadSceneAsync(11);
  }
  public void RPM()
  {
     SceneManager.LoadSceneAsync(12);
  }
  public void VolPiesaPrel()
  {
     SceneManager.LoadSceneAsync(13);
  }
  public void BackB()
  {
     SceneManager.LoadSceneAsync(1);
  }
}

Asset Labels
```

Fig. 10. Example of used script

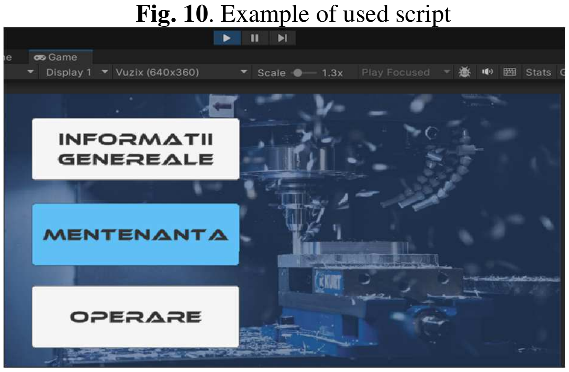


Fig. 11. Unity Simulator

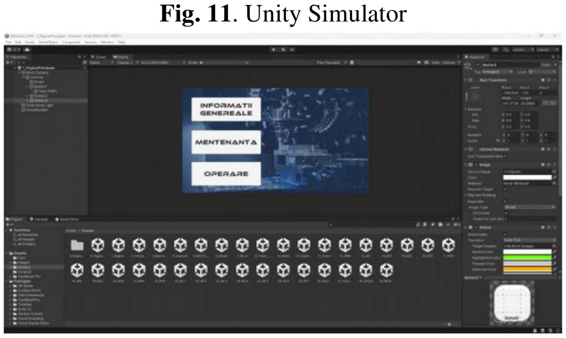
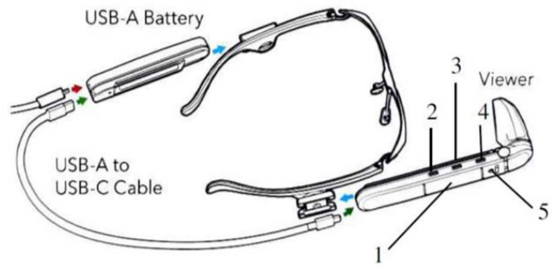


Fig. 12. Unity project



1 – Touch pad
2 – Navigate back
3 – Navigate center
4 – Navigate front
5 – Power button

Fig. 13. Vuzix M400

Running the application in Unity after each iteration. The programs can be tested in the simulator by going to the Scene, Game area and pressing the Play button – fig. 11.

6. Building the APK and installing it on the glasses.
7. Updating the application after the tests on the glasses.

Part of the Unity project can be seen in fig. 12.

3.4 Test

After development, the application was downloaded and installed on a pair of Vuzix M400 Smart glasses. The scheme of connection and navigation is shown in figure 13.

A focus group was selected for this test and respondents were instructed to use smart glasses: to start/stop the glasses, to launch an application and to navigate in the menu.

Method 1: Documentation-Based Learning

The first method involved providing operators with comprehensive documentation related to the CNC machine. This documentation encompassed vital information required for operating the machine effectively. Operators were given one hour to explore the documentation and locate specific information.

During this phase, operators delved into the provided materials, diligently searching for key details such as machine specifications, operating procedures, tooling instructions, and safety guidelines. They navigated through technical jargon, diagrams, and textual explanations, aiming to absorb as much knowledge as possible within the given timeframe.

Method 2: Augmented Reality Training

In the second method, operators were introduced to Vuzix glasses, an advanced augmented reality (AR) device.

Equipped with these AR glasses, operators engaged in a specialized training program designed to enhance their understanding of CNC machine operations.

In figure 14 the subject using Vuzix smart glasses to find the coolant filters can be seen.

With the AR glasses on, operators immersed themselves in a virtual environment where digital information was overlaid onto their real-world view. Within this augmented reality space, operators could interact with 2D images, visualizations, and step-by-step instructions in real-time.

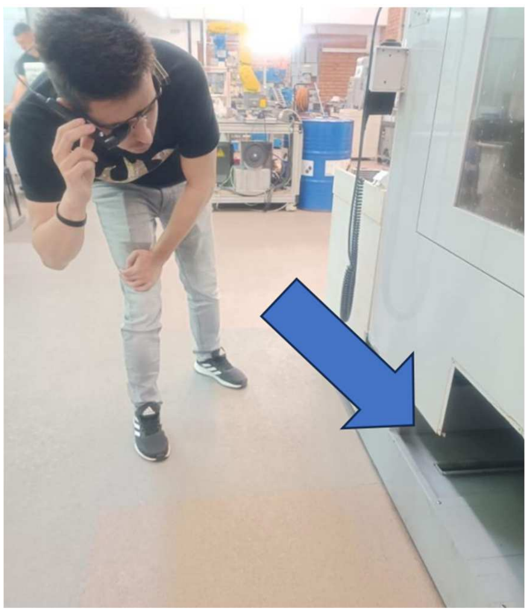


Fig. 14. Identifying the coolant filter using smart glasses

During the test, the sanitary norms prevailed. After each test, the touched objects were sanitized, and the room was continuously ventilated.

3.5 UI optimization

Optimization of the user interface aims to create and improve the interaction between the user and the CNC machine in an efficient, intuitive, and pleasant manner. This process purpose is to provide a satisfying and productive user experience by minimizing errors, facilitating the understanding of presented information, and enabling a seamless interaction with system functionalities.

In the questionnaires collected, the respondents recommended us to change the colour of some pairs of backgrounds and buttons so that the image is more readable.

3.6 UI retesting

After the requested changes were made, the application on the glasses was updated and a new group was created to retest the application.

The degree of acceptance has increased from 74% to 92%.

4. RESULTS

Upon completion of both training methods, we evaluated the operators' performance and learning outcomes, illuminating the strengths and weaknesses of each approach in the context of industrial training for CNC operators.

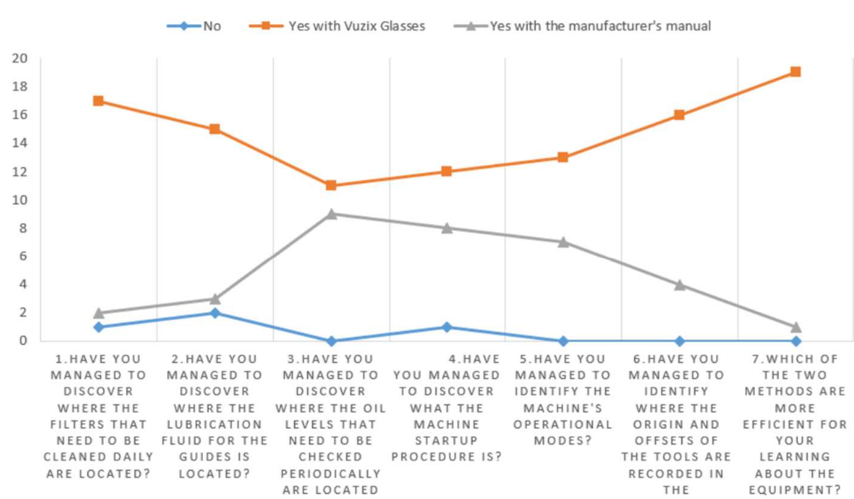


Fig. 15. Identifying the coolant filter using smart glasses

In the documentation-based learning method, operators showcased their ability to navigate through written materials and extract relevant information. While some operators successfully located the required details, others faced challenges in comprehending technical terminology and translating it into practical knowledge. This method relied heavily on the operators' reading and comprehension skills.

Conversely, the augmented reality training method offered a dynamic and engaging learning experience. The immersive nature of the AR environment allowed operators to visualize and interact with complex machine components and receive real-time guidance. This interactive approach facilitated a deeper understanding of CNC operations and enabled operators to grasp concepts more intuitively.

In figure 15, you can see in the form of a graph the comparisons between the two training options: manual vs. AR with smart glasses.

5. CONCLUDING REMARKS

The comparative investigation into traditional documentation-based learning and augmented reality training methods underscores their unique strengths and weaknesses in facilitating CNC operator training within the industry.

The enduring value of traditional documentation cannot be undermined, given its reliance on operators' capabilities to glean information from text-based materials. On the other hand, the advent of augmented reality technology provides a more dynamic, immersive, and interactive learning landscape, which significantly bolsters the understanding and recall of complex ideas — a critical factor for CNC industry professionals.

By capitalizing on the merits of each learning style, industrial training initiatives can utilize a hybrid strategy. This would involve harnessing the detailed and extensive content provided by traditional documentation, while also leveraging the interaction and experiential learning afforded by augmented reality.

The integration of augmented reality into the CNC training paradigm opens new avenues for transforming traditional learning processes. It equips operators with the requisite expertise to thrive in the evolving landscape of the modern manufacturing sector.

6. ACKNOWLEDGMENTS

Our sincerest gratitude is extended to all the individuals who participated in various testing phases of this study.

8. REFERENCES

[1] Kovalev, I., Nezhmetdinov, R., & Kvashnin, D., *Development of a Mobile Application for Training Operators to Work with Machine Tools with CNC Systems Using Augmented Reality*. In International Russian Automation Confe-rence (RusAutoCon) (pp. 863-867). Sochi, Russian Federation: IEEE. https://doi.org/10.1109/RusAutoCon52004.2021.9537320, 2021.

[2] Köroğlu, O. *En yaygın iletişim ortamında artırılmış gerçeklik uygulamaları*. In XVII. Türkiye'de İnternet Konferansı, 2012.

[3] Güler, O., & Yücedağ, I. *Developing an CNC lathe augmented reality application for industrial maintenance training*. In 2nd International Symposium on Multidiscipli-nary Studies and Innovative Technologies (ISMSIT) (pp. 1-6). Ankara, Turkey: IEEE. https://doi.org/10.1109/ISMSIT.2018.8567255, 2018.

[4] Gloria O., *Million Consumers Will Shop in Augmented Reality Online and In-Store by 2020*, https://www.gartner.com.

[5] Tim M., *AR/VR's $80 billion-plus market could split before it consolidates*, https://venturebeat.com).

[6] Bartos, D., Brad, S., Hapca, R. *Systematic design method of ux using smart glasses for the effective application of augmented reality in digital production*, Acta Technica Napocensis, Applied Mathematics, Mecha-nics, and Engineering, Vol. 64, Issue II, pp. 275 (2021)

Îmbunătățirea pregătirii operatorilor de pe maşinile de frezat CNC prin utilizarea ochelarilor inteligenți de realitate augmentată

Rezumat: Domeniul în evoluție rapidă al tehnologiei Realității Augmentate (AR) oferă un potențial semnificativ de a revoluționa metodele tradiționale de antrenament în diverse industrii. Acest studiu investighează utilizarea AR, în special a ochelarilor inteligenți, pentru a îmbunătăți eficiența instruirii și performanța operatorilor de mașini de frezat CNC. Întrebarea de cercetare urmăreşte să înțeleagă modul în care integrarea tehnologiei AR sub formă de ochelari inteligenți poate îmbunătăți procesul de învățare și poate optimiza experiența generală de formare pentru operatorii de mașini de frezat CNC. Metodologia noastră implică o abordare cuprinzătoare pentru dezvoltarea, testarea și îmbunătățirea unei aplicații AR adaptate pentru funcționarea mașinii de frezat CNC, integrată perfect cu ochelari inteligenți. Aplicația utilizează tehnologii avansate AR, cum ar fi afișarea informațiilor în timp real și asistența sensibilă la context, pentru a oferi o experiență de învățare captivantă. Un eșantion de grup de cursanți participă la un studiu controlat pentru a evalua eficacitatea antrenamentului asistat de AR în comparație cu metodele tradiționale de antrenament. Analiza cantitativă a datelor dezvăluie o îmbunătățire cu 30% a eficienței antrenamentului și o reducere cu 25% a perioadei de antrenament, ceea ce duce la îmbunătățirea performanței operatorului și la reducerea ratelor de eroare. O discuție amănunțită a acestor constatări evaluează implicațiile lor pentru formarea mașinilor de frezat CNC, inclusiv avantajele și limitările abordării asistate de AR, precum și recomandări pentru cercetări viitoare pentru a explora în continuare potențialul AR în contexte de formare industrială. O discuție amănunțită a acestor constatări evaluează implicațiile lor pentru formarea mașinilor de frezat CNC, limitările studiului și recomandările pentru cercetările viitoare.

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