Virtual Reality Solutions Employing Artificial Intelligence Methods: A Systematic Literature Review

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Although there are methods of **artificial intelligence (AI)** applied to **virtual reality (VR)** solutions, there are few studies in the literature. Thus, to fill this gap, we performed a systematic literature review of these methods. In this review, we apply a methodology proposed in the literature that locates existing studies, selects and evaluates contributions, analyses, and synthesizes data. We used Google Scholar and databases such as Elsevier's Scopus, ACM Digital Library, and IEEE Xplore Digital Library. A set of inclusion and exclusion criteria were used to select documents. The results showed that when AI methods are used in VR applications, the main advantages are high efficiency and precision of algorithms. Moreover, we observe that machine learning is the most applied AI scientific technique in VR applications. In conclusion, this paper showed that the combination of AI and VR contributes to new trends, opportunities, and applications for human-machine interactive devices, education, agriculture, transport, 3D image reconstruction, and health. We also concluded that the usage of AI in VR provides potential benefits in other fields of the real world such as teleconferencing, emotion interaction, tourist services, and image data extraction.

CCS Concepts: • **Computing methodologies → Search methodologies** • **General and reference → Surveys and overviews** • **Computing methodologies → Virtual reality**; *Machine learning approaches*;

Additional Key Words and Phrases: Virtual reality, artificial intelligence, Industry 4.0, literature review

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1 INTRODUCTION

Virtual reality (VR) integrates multimedia, sensor, display, human-machine interaction, ergonomics, simulation, computer graphics, and **artificial intelligence (AI)** technologies to expand human perception and allow users to have an immersive experience by interacting with generated **virtual environments (VEs)** [1]. Second, VR is an advanced computer technology that can provide users with multiple intuitive sensations while simulating mechanisms in a physical or imaginary world [2]. Recently, VR has developed into a practical tool for manufacturing industries because of the rapid development of manufacturing technology and constant changes in customer demands, modern manufacturing enterprises face significant pressure from global competition [1].

The paper [2] claimed the following: VR devices in the early decades were expensive and inefficient, but the development of current hardware has decreased its cost and size, beyond which the software became more efficient; today, VR applications can provide users with immersive sight beyond reality, hearing, touch, and even the ability to interact with virtual objects. Thus, VR has undergone significant development in the last few years, which has brought interest from industry and academia. However, VR is an emerging technology with many issues that require additional research.

Human history is marked by the progression of media in communication, which is one of the most recent steps in the use of VR [3]. Moreover, [3] stated that human history started with people painting on cave walls and sharing stories in the community. Thus, it was the importance of communication that raised the storyteller to a position of popularity within a community.

Nowadays, VR is defined as the one in which the observing participant is fully immersed and can interact with a completely synthetic world that can mimic the properties of some real-world environments, existing or fictional [4]. VR is an interactive tool that replaces real objects with its virtual correspondent, thus using virtual tools to solve problems from the real world [5].

AI is widely used throughout personalized recommendations for people in e-commerce, economy, finance, logistics, manufacturing, agriculture, language translation, marketing, production, and supply chain [6]. Moreover, it can help smart cities, interpret thermal imaging, health, and collaborate in other areas. AI is a tool built into a machine that has the ability to create, plan, learn, process logic, and ratiocinate in the same way that a human does.

The techniques outlined by [6] were neural networks (the most popular, which can be seen across all fields), fuzzy logic, intelligent agents, genetic algorithms (another popular technique), data mining, swarm intelligence, simulated annealing, and automated planning. Furthermore, techniques less frequently located in the literature such as association rules, tree-based models, hill climbing, k-means clustering, expert systems, heuristics, robot programming, stochastic simulation, Bayesian networks, rule-based reasoning, decision trees, and Gaussian models were presented in the paper [6]. The work described [6] highlighted that double or multiple AI techniques were used in two ways: by combining them and creating a hybrid and by employing them sequentially.

The studies described below show applications found in the literature that have been used in the industry or other areas, applying the technology with VR, AI either both. A systematic literature review to investigate VR in usability testing of products under development in the automotive sector was conducted in accord [7]. The benefits and limitations were compared with those of traditional usability testing.

The paper [4] characterized the current knowledge about the use of VR for the analysis of ergonomic problems related to people's interactions with their work environment. The workplace is an important part of manufacturing systems, and workers typically need to carry out various activities for many hours at their workplace [1]. The work [8] identified trends, challenges, and opportunities for improving VR and **augmented reality (AR)** technologies used in agriculture.

These previous studies presented search strategies that have a specific focus on VR or AI. Thus, we decided to present a practical literature review of intelligent VEs. The focus of attention has been on the integration of AI and VE to obtain greater usability and realism from interfaces, exploring the combination of 3D objects and intelligent entities [9]. In this sense, this work conducts a systematic review using AI methods, especially in the applications of VR. The findings will make it possible for researchers interested in AI methods applied to virtual reality to use systematic literature review.

The remainder of this paper is organized as follows. Section 2 presents the related works of AI and VR about methods, limitations, and challenges for solutions in several areas. Section 3 describes the study's methodology. Section 4 describes the results, discussion, and analysis of the study. Finally, Section 5 presents the conclusions and final considerations.

2 RELATED WORK

This section describes the contributions to the related research areas in the context of VR and AI. The papers of literature identified trends, challenges, and opportunities for improving VR technologies used in several sectors. Moreover, several papers described AI techniques that can address the current gap in the productive sector. Thus, our work was inspired by these related works presented here that include procedures, address similar problems, and analogous methodology.

Recent developments in immersive technologies, in terms of visualization, interaction, and degree of immersion, which can be used in head-mounted displays, have made VR increasingly attractive not only to academics, but also to other areas. More recently, the entertainment industry has stimulated the development of most VR technologies [5]. A VR system in the logistics for maintenance training of a specific diesel motor, which offered a low-cost and efficient solution for this training, was presented by [10].

The system developed by [10] is used for locomotives responsible for transporting ore in a Brazilian mining company. It was designed using a game engine and consisted of a 3D model for VR and an **extensible markup language (XML)** module for the motor part selection.

VR technology has also been widely used in industries such as healthcare, entertainment, culture, sports, engineering, military, and manufacturing, where it has received significant research attention as a novel technology [1]. As outlined above, this immersion describes the involvement of a user in a VE. After some time immersed in VR, the real world often becomes disconnected, thus providing a sense of "being" in the real world [11].

The paper [9], presented an intelligent, adaptable, 3D, and VE for distance learning that explores the resources of VR, seeking to increase the degree of interactivity between users and the environment. A process of automatic categorization of contents was applied in the creation of content models, used in the spatial organization of the same ones in the environment [9]. Moreover, [9], an intelligent agent was presented which assists users during navigation in the environment and retrieves relevant information.

The paper [12] proposed the role of **human–machine interaction (HMI)** technologies, including both AI-and VR-enabled applications in the tourism industry. The study showed that HMI devices were integrated with AI and VR and had a significant effect on overall service quality, leading to tourist satisfaction and loyalty.

AI, artificial techniques, and intelligence techniques were used to create autonomous creatures and agents that can interact with environments and predict the possibilities [13]. These techniques, combined with effective means for their graphical representation and interaction of various kinds, have given rise to a new area, which the authors of [13] called intelligent VEs.

Conforming to the paper of [13], several factors that allow the use of intelligent VEs, particularly fields of exploration, including intelligent and autonomous agents, make such an obvious step to take. Cooperating with this environment, the continuing growth in the amount of computing power not only supports a much higher degree of visual realism but also leaves a gap for processing power that can be used to add intelligence.

A procedure was presented to incorporate AI in VEs to deal with visualization and intelligence modules using a distributed approach [14]. Scalable applications were built at both the graphic level and the multiagent system level. An architecture was designed that allowed agents to be integrated into the virtual world. During the procedure described by [14], a framework was integrated with multiagent systems and a VE for developing intelligent VEs, which has been prominent.

The paper [15] addressed issues of VR technology combined with AI and the impact of these technologies to create a new dimension to the business, in addition to the influence on industries in the next few years. Finally, this study shows the infrastructure challenges of VR and AI: hardware, staff, software and algorithms, storage, connectivity, security, privacy, intellectual property rights, and ethics.

The study [15], highlighted the following topics: (1) the industries need to create and adapt to new technologies and they need to revisit their existing products to update them; (2) an increasing number of customers are using online shopping, increasing user information that will be stored in the big data archives; (3) future products, including home appliances, will have these technologies in everyday activities and they are the businesses that will monetize the mixed realities; (4) convergence of these technologies will play a key factor in determining the marketplace of such products; (5) natural language processing and intelligence-powered voice recognition systems will slowly replace the need for secure login to appliances and communication in business departments; and (6) the emotions will be read continuously by AI incorporated in smart video conferences, thereby making it more interactive to users.

The work [16] presented the concept of several fields as deep learning and semantic web in line with the potential brought about by their combination. The study resulted in the development of a user-friendly and user-centered intelligent application. The paper [6] sought to conduct a systematic review to identify the contributions of AI to **supply chain management (SCM)** to address the current scientific gap of AI in SCM. Moreover, the study [6] determined the current and potential AI techniques that can enhance both the study and practice of SCM.

The literature analyzed here brings great knowledge about methods, discussion, implications, and limitations in the use of AI for solutions in VR. Questions about which AI technique is most applied, which fields employ AI, how AI can contribute to the new trends and opportunities, and more broadly "Is the use of AI particularly relevant to help on intelligent manufacturing or logistics?" come to light. Answering these questions requires multidisciplinary perspectives and a literature exploration.

3 REVIEW METHODOLOGY

In the following sections, we describe a proposed approach in the systematic literature review in relation to the methods of AI that use VR.

3.1 Guidelines

We used the systematic literature review guidelines proposed by authors of [17], which were used to locate existing studies, select and evaluate contributions, analyze, and synthesize data. This methodology even reports evidence in such a way that allows reasonably clear conclusions to be reached about the literature findings.

In this sense, we conducted a preliminary study in the existing literature into the following areas of AI and VR, to answer the following questions: How does AI contribute to solutions in VR? Next, we selected search engines, databases, and search strings. In this search, we considered the inclusion and exclusion criteria from a preliminary search. The criteria included the period, the context of the geographical region, fields of AI, and types of documents of literature (thesis, monographs, books, technical documents, and reports, theoretical papers, and applied papers).

We considered only the applied papers. To analyze and synthesize several applied papers, we chose a set of characteristics to feed back to our research question. The characteristics chosen were the AI techniques used, the applications in industry, trends and opportunities, technological skills, and intelligent manufacturing or logistics.

The information in the papers [19–232] was collected using a questionnaire that asked the following questions: authors, title, year, country, type paper (applied paper or review), AI techniques, application fields, advantages, limitations, trends and opportunities, and economic sector (manufacturing or logistics). In a review study, the goal is to collect data by collecting valuable information from the literature.

To ensure the integrity of the collected data, 12 authors worked simultaneously to complete the extracted data to guarantee the upstanding data collection. Thus, we can perform further analysis with the collected data, which will be discussed in the following sections.

Finally, the results are presented in a summary of the reviewed literature on the research questions. A systematic literature review process is illustrated in Figure 1.

3.2 Research Questions

This study systematically reviews the state-of-the-art methods in terms of the contributions of AI methods for VR solutions. VR has been developed in industry, education, intelligent manufacturing, services, logistics, and other fields with rapid development in its technology and customer demands that are under pressure from global competition. Some studies of the literature bring the concepts of VR, deep learning, neural network, or other technologies of AI in a way that combines these applications.

Besides, these studies are in development to examine the AI implementations and the design elements of the VR applications. Hence, in this paper, we focus on the use of AI methods, particularly in VR applications, to answer the following research questions (RQ1 to RQ4). The (RQ5) fifth research question targets two sectors belonging to the Brazilian strategic sectors. In this sense, the authors are interested in these sectors.

The review will then contribute to the identification of new trends and opportunities, the most frequent problems, applications, frameworks, and potential benefits. We raised the following **research questions (RQs)** based on the aforementioned goal:

- RQ1: Which AI techniques are most applied for VR?
- RQ2: Which fields employ AI in the VR based applications?
- RQ3: What are the advantages and limitations of using AI methods in VR-based applications?
- RQ4: How can AI contribute to new trends and opportunities for VR-based applications?
- RQ5: How can AI and VR help on intelligent manufacturing or logistics?

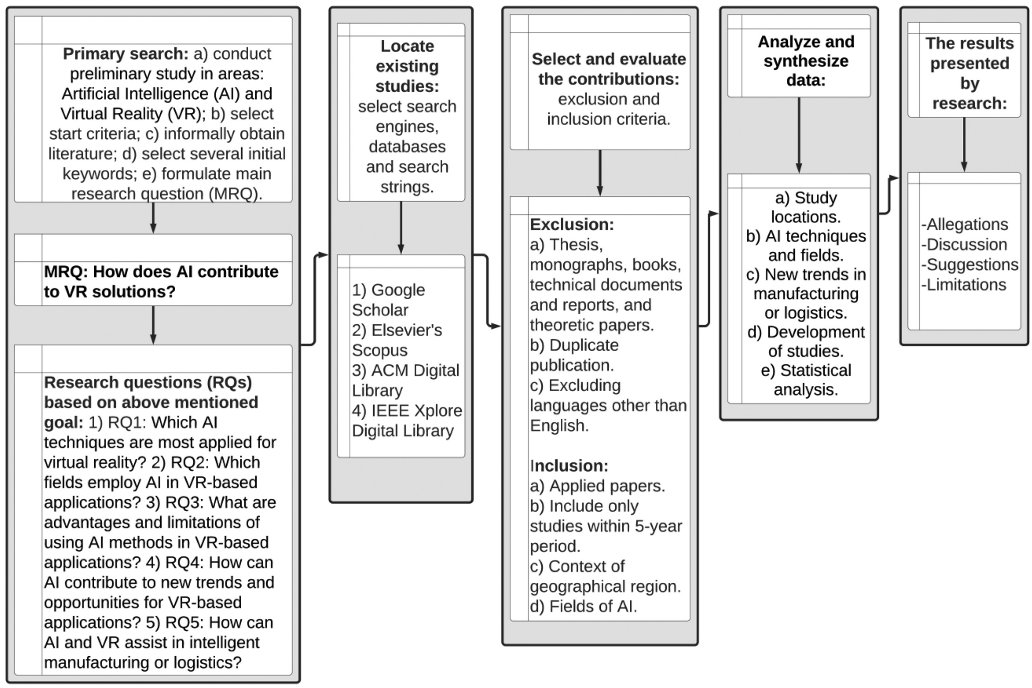

Fig. 1. Steps of systematic literature review, adopted from [6].

3.3 Search Strategy

Search engine:

- Google Scholar

Databases:

- Elsevier's Scopus
- ACM Digital Library
- IEEE Xplore Digital Library

First, we used **Google Scholar (GS)** for searching literature documents such as papers, chapters, technical reports, theses, monographs, and books. This search was given an initial conceptual shape to the theoretical background of our research. We obtained 9,320 results from the literature with the search engine GS that used the string in the Boolean logic called the initial keywords, as follows.

Initial Keywords: "Artificial Intelligence" AND "Virtual Reality" OR "Augmented Reality" OR "Industry 4.0" OR "Augmented human" OR "Supply chain management" OR "Systematic literature review" OR "Intelligent virtual environments" OR "Adaptive interfaces" OR "User modeling" OR "Industrial products" OR "Mixed Reality Simulation" OR "Computing" OR "Wearable Technologies" OR "Intelligent Manufacturing" OR "Technology" OR "Smart Factory" OR "Industrial Digitalization" OR "Machine learning" OR "Deep learning" OR "Human computer interaction."

For the interdisciplinary and collaborative search process, we used databases such as Elsevier's Scopus, ACM Digital Library, and IEEE Xplore Digital Library, to define more refined search terms. These databases guarantee important research and intelligent tools to monitor and analyze beyond the visualization of research results. Only applied papers were selected with the following metadata: title, abstract, and keywords.

Table 1. Systematic Review Sources: Search Engine, Academic Databases, Strings, and Number of Recovered Documents

Research source	Search string	Documents
Google Scholar	“Artificial Intelligence” AND “Virtual Reality” OR “Augmented Reality” OR “Industry 4.0” OR “Augmented human” OR “Supply chain management” OR “Systematic literature review” OR “Intelligent virtual environments” OR “Adaptive interfaces” OR “User modeling” OR “Industrial products” OR “Mixed Reality Simulation” OR “Computing” OR “Wearable Technologies” OR “Intelligent Manufacturing” OR “Technology” OR “Smart Factory” OR “Industrial Digitalization” OR “Machine learning” OR “Deep learning” OR “Human computer interaction.”	9,320
Elsevier’s Scopus ACM Digital Library IEEE Xplore Digital Library	(artificial intelligence AND virtual reality) OR Industry 4.0 OR systematic literature review OR intelligent virtual environments OR intelligent manufacturing OR smart factory OR machine learning OR deep learning.	214*

*The total number resulting from three databases. Repeated papers were eliminated.

Garcia, Gattaz and Gattaz [18] highlighted the importance of titles, abstracts, and keywords because these components establish the readers’ first contact with the research. So, in the next try, we concentrated on a set of strings to increase relevance using filters, such as “Artificial Intelligence” and “Virtual Reality”.

These two words were combined with another set of strings using a database. The last set of strings searched within these filters was “Industry 4.0,” “Systematic literature review,” “Intelligent virtual environments,” “Intelligent Manufacturing,” “Smart Factory,” “Machine learning,” and “Deep learning”.

Thus, the strings used with Boolean logic in the database were (artificial intelligence AND virtual reality) OR Industry 4.0 OR systematic literature review OR intelligent virtual environments OR intelligent manufacturing OR smart factory OR machine learning OR deep learning. We obtained 214 results from applied and review papers.

In Table 1 is shown the systematic review sources, according to the process outlined by Denyer and Tranfield [17] as described above. In this sense, from the search engine Google Scholar, 9,320 candidate documents were pointed out, in our initial analysis. Then, from the three academic databases Elsevier’s Scopus, ACM Digital Library and IEEE Xplore Digital Library, 214 applied and review papers were identified for further analysis.

3.4 Exclusion and Inclusion Criteria

We selected exclusion and inclusion criteria to obtain relevant documents for our research. Our goal is to select scientific works where we can find recent advances in the subject of the review. Moreover, we intend to focus on applied research where we can identify the potential use and the major beneficiaries of the technology.

We have chosen the applied papers because the research in this field has objectives to solve a specific problem in industry, commerce, services, logistics, process, or systems. The applied papers involve the practical application providing innovative solutions to questions that are emerging in a society.

To analyze and synthesize several applied papers, we chose a set of characteristics of feedback to our research question. The characteristics chosen were AI techniques used applications in industry, intelligent manufacturing, logistics, and so on.

Fig. 2. Quantitative paper distribution according to the year of publication.

We narrow the focus of our search so that the information retrieved from the databases is limited according to the last five published papers. Thus, the focus of our research ensures that this study retrieve the results published recently. In this sense, we introduce a limiter such as date to retrieve a current results list about the findings, technological skills, trends, and opportunities for VR-based applications that use AI.

We kept the inclusion geographical region because it shows the significance and impact that the papers have in the world, their widespread use in teaching, and the development of research in the geographical region in a broad way.

In this sense, we introduced the demands so the documents would be reliable in our systematic review. Therefore, the exclusion and inclusion criteria were as follows:

Exclusion Criteria:

- Thesis, monographs, books, technical documents and reports, and theoretical papers.
- Duplicate publication.
- Excluding languages other than English.
- Review papers.

Inclusion Criteria:

- Applied papers
- Include only studies within the 5-year period.
- The context of the geographical region.
- Fields of AI.

4 Results AND DISCUSSION

The results of the study, according to the collected data and the research questions (RQ1 to RQ5) are presented. Several papers ([19–232]) were used to respond to each question.

4.1 Collected Data Results

Beyond the previous search strategy, we also considered other relevant information regarding the year of publication, geographical region, economic sector, and field of research. In the results evaluated in this section, we only considered applied papers. From 214 papers, we excluded 36 review papers according to our exclusion criteria. Figure 2 shows the paper distribution according to the year of publication.

The year of publication revealed an increased interest in the combined use of AI in VR-based solutions. The growth was substantial in 2020, representing 44% of the publications in the last

Table 2. Quantitative Paper Distribution According to the Year of Publication

Country	Papers	%
China	90	50.6%
USA	31	17.4%
South Korea	8	4.5%
United Kingdom	8	4.5%
Germany	6	3.4%
Australia	4	2.2%
Spain	4	2.2%
Canada	3	1.7%
Austria	2	1.1%
Finland	2	1.1%
France	2	1.1%
Italy	2	1.1%
Japan	2	1.1%
Switzerland	2	1.1%
Vietnam	2	1.1%
Belgium	1	0.6%
Brazil	1	0.6%
Chile	1	0.6%
Deutschland	1	0.6%
Egypt	1	0.6%
Malaysia	1	0.6%
Poland	1	0.6%
Russia	1	0.6%
Scotland	1	0.6%
Taiwan	1	0.6%
Total	**178**	**100.0%**

five years. The distribution of papers according to the country of the main research institution is presented in Table 2.

Education is the economic sector most present, followed by manufacturing and logistics, as shown in Table 3. This scenario is highly correlated with the research fields, as shown in Table 4, where education and transport services appear in the first and third positions.

In Table 4, health is third place among the research fields, underlining the fact that health areas are a research matter shared with different economic sectors beyond the health sector.

4.2 Research Questions Results

We will present the findings of a review of 178 selected papers that addressed the research questions RQ1–RQ5. Thus, a discussion of the important findings will be conducted in detail for each research question.

RQ1: Which AI techniques are most applied for VR?

One AI topic in particular, **Machine Learning (ML)** techniques deserves particular attention since it represents most of the works of this review [20–30, 43–52, 78–89, 107, 115–124, 126–147]. The ML techniques correspond to a great variety of techniques: neural networks, deep networks,

Table 3. Quantitative Paper Distribution According to the Economic Sector

Economic Sector	Papers	%
Other	49	27.5%
Education	45	25.3%
Manufacturing	40	22.5%
Logistics	19	10.7%
Health	16	9.0%
Telecommunication	9	5.1%
Total	**178**	**100.0%**

Table 4. Quantitative Paper Distribution According to Fields of Research

Fields of research	Papers	%
Education	73	41.0%
Other	34	19.1%
Health	31	17.4%
Transport Services	13	7.3%
Environment	8	4.5%
Wireless Communication	5	2.8%
Mining Industry	4	2.2%
Civil Construction	4	2.2%
Telecommunication	3	1.7%
Manufacturing Industry	3	1.7%
Total	**178**	**100.0%**

support vector machines, k-means, decision trees, genetic algorithms, data mining techniques, and pattern recognition methods. Among the ML techniques, deep networks represent most of the papers. Some examples of such works are described below.

The work presented by [107] implemented an AI approach for video processing and action recognition classifications, in which the best recognition rate was 88.3%, 87%, and 86.4% of the **support vector machine (SVM)**, neural network and convolutional network methods, respectively.

A deep network-based method for estimating **high-dynamic-range (HDR)** illumination from a single RGB image was developed and outperforming other approaches in the literature in accord to [129].

Recurrent Neural Networks have shown to be suitable for real time character control in virtual environments, in terms of the trajectory of the character according to a desired path [22].

Neural networks were also employed to learn locomotion skills for a virtual character [169], including walking, running, jumping, and so on. Performance results were too dependent from available datasets to train the network weights.

The concept of machine learning for image reconstruction and 3D environments was used the most [223–232]. A decision and support system for therapists using machine learning, AI, images, and motion recognition was described by [226].

It was also observed that the most used AI technique is machine learning [54–58, 60–69, 72, 73, 77]. In the abovementioned fields, deep learning and neural networks are the most applied subfields of machine learning. However, it is worth mentioning that other studies also addressed aspects related to intelligent robotic applications [61, 68, 77].

Furthermore, we analyzed the works of [173], [174], [176–180], [182–187], and [189–194]. Therefore, we can conclude that the most used technique is machine learning, and in its subfields, deep learning and neural networks are most used.

After the analysis of the other papers, machine learning is prioritized when AI is employed in VR projects [90, 91, 93–95, 98, 100–102, 105–108, 112, 114], with emphasis on **convolutional neural networks (CNNs)** [90, 91, 93, 98, 110, 150, 155, 163, 168]. Deep learning was used in several papers [91–3, 95, 97–100, 104, 107, 110, 112, 114, 161, 165, 166, 169, 170, 172].

RQ2: Which fields employ AI in the VR based applications?

We give emphasis to the following papers [140, 142, 147], and the results revealed that machine learning has been used in a variety of real-world applications such as teleconferencing, human-robot interaction, behavior recognition, and cognitive load measurement. A novel binaural sound source localization method based on a time-frequency CNN with multitask learning to simultaneously estimate azimuth and elevation was proposed in paper [140].

Sound source localization is a key component of computational auditory scene analysis, and can be applied to several audio applications, such as hearing aids, teleconferencing, and human-robot interaction in VR and real-world environments.

The paper of [147] tested cognitive load measurement by applying multiple machine learning algorithms using data collected during VR-based driving in adolescents with **autism spectrum disorder (ASD)**. However, the work of [142] used machine learning algorithms for behavior recognition in marine zooplankton. The study [142] further discussed the establishment of standard data motion behaviors of copepods from the image-sampling system to subsequent image processing, in particular, the motion detection algorithm played an important role in acquiring raw video fragments of motion.

Besides, [20] reports on the use of machine learning to obtain data through human-machine interaction, improving the involvement and experience of the tourist all service points that interact directly with them. Another use of this tool is through natural language processing that involves morphology, syntax, and semantics, understanding the user and being able to maintain a coherent dialog.

We approach studies such as [198] and [199] that can better address different applications for integration between VR and AI. The paper [198] proposed a remote sensing image data extraction and target recognition method, which is essential for agricultural development and construction planning. A mechanism to control a **micro aerial vehicle (MAV)** by users' gaze was proposed by [199]; MAVs are used in various fields, such as commercial aerial surveillance and disaster relief operations.

Some methods for 3D image reconstruction can be applied in the specialized field of recognizing people in motion [223–227, 229–232]. In the architecture and construction industry, the methods can show the results of a project to the client before their implementation [229–232]. The work of [227] employed 3D photography and reconstruction techniques that could be applied to user interaction with 3D environments.

In several studies, such as [69] and [73], the technologies developed do not have a specific field of application. For example, [69] developed a practical real-time hand tracking system to control VR experiences. This research used neural network architectures to detect hands and estimate hand key-point locations. A system to capture hand poses using a stretch-sensing glove, presenting high accuracy without requiring any external optical setup, such as a webcam or cameras was developed by [73].

However, studies by [63] and [68] are worth highlighting. The paper [68] developed a system that estimates human facial expressions in real time to help treat children with autism.

This CNN-based system can recognize facial expressions of multiple objects simultaneously from a webcam. Additionally, the study of [63] presented a direct application in the fields of environment and botany. In this study, a CNN-based method was proposed as an automated system for identifying plant species, which is a complex and time-consuming task to be performed by humans.

In other studies, the areas of operation are wide, ranging from the steel sector [173] and real-time mapping [191]. AI in VR systems is mostly used to improve transportation services [90, 91, 93–95, 97, 100, 106], wireless communications [104, 105, 108, 113], and visual quality [150, 161, 166, 169, 170]. A study by Zhang, Fei and Yang [150] improved the selection of viewports, rendering 3D models with better visual perception and esthetics. According to [161], this approach can fully automatically find and replace segment salient objects in each 360° scene.

Additionally, [166] developed a method to record 3D videos that can change its perspective, increasing the sense of immersion. The paper [169] synthesized natural motion for virtual characters which improving naturalness in VREs. Finally, the study of [170] generated accurate ambient occlusion maps using deep neural networks, improving the perception of textures in 3D models.

In addition to visual experience and transport services, other fields have been explored. AI was used to improve the rendering efficiency by extracting encoding information from lower-resolution objects [155] and reducing the number of iterations used to select the best view [163]. Hand tracking and hand pose estimation were addressed [165, 168]. However, in [172], the user's arms were included in the VR simulation to improve self-perception.

Additionally, we can mention the chemical industry [96], Arabic sign language [98], agriculture [100], smart investment [101], human action [107], design layout [110], ground target tracking [111], visual impairment [92], energy transmission and distribution, **ground vehicles (GVs)** and **unmanned aerial vehicle (UAV)** positions [99], hand tracking [102], human movement [112], and health and emotion interaction recognition [114].

An important use of machine learning is in Industry 4.0 [43], improving the competitiveness of companies and regions, increasing productivity, improving the economy of production, accelerating industrial growth, and favorably changing the profile of the workforce.

The cyber security area uses a defensive method with stage-wise hints training, and noise injection can still work even under current strong attackers [121].

Another use is in communication [47], which allows a better, faster, and more efficient communication between devices that currently operate on 5G and enables better communication between data used in machine learning and AI. In addition to Industry 4.0, cyber security, and communication, machine learning has significantly changed, but in medical and healthcare systems has improved significantly.

The modeling and control of complex systems were improved [45], already [50] was providing substantial improvements in the social skills of children with ASD, and [115] provided accurate, on-demand, and personalized care.

Machine learning can reduce clinic visit requirements while offering continuous care and reducing costs. Machine learning was used to improve the use of VR by creating a safer and better experience by predicting sickness and motion sickness symptoms before they occurred [78, 80, 81, 86, 116].

One important field of machine learning application is education, and [48] devised methods to improve the computing power of mobile devices and a heterogeneous mobile cloud service. The paper [87] devised methods to distinguish between professional and amateur videography works, and its video esthetics is worthwhile and has interesting virtual applications.

According to [89], an image recommendation method based on an implicit support vector machine can meet the personalized needs of different users. Two distinct fields combined civil construction and education to obtain empirical research on the application of predictions about the conditions of a bridge up to 24 h before the events [44]. It allows them to make decisions based on the forecasts presented by the systems, which is a good opportunity for future research.

RQ3: What are the advantages and limitations of using AI methods in VR-based applications?

The papers that used AI tools for VR applications mostly had the same limitation in capturing the initial data [34, 20]. The analytical models helped to accurately predict the customer's behavior and the probability of repetition of the behavior [20], as well as a higher speed of information transmission, which allows simultaneous tasks to be performed [34].

For this inquiry, we emphasize two papers [206] and [214]. These studies demonstrate the advantages of AI use, mainly in the effective use of data relayed by external sources and the use of datasets to adapt to different contexts. However, it is also found to be a significant limitation in both the computational cost, which may hamper scalability, and the lack of larger datasets, which may hamper the network's adaptability.

The "LookinGood" system [223] emphasizes the use of AI and VR tools to produce high-quality outputs. Nevertheless, the lack of data to feed the system is a major disadvantage of using AI in this application. It is important to say that this is not true for all AI based systems (e.g., applications with rule-based AI).

A great advantage of using AI in VR applications is that it can improve the human-machine interaction, especially in situations involving intelligent robotic applications. For example, [61] developed a method to estimate the engagement of participants in a group interaction so that the autonomous system can generate engaging behaviors. This technology, which is applied in the context of VR, can bring interesting evolution.

Furthermore, note that the developed methods have a higher success rate and superior performance compared to more traditional applications [57, 58, 60, 67, 68]. The work of [58] proposed a gesture recognition algorithm based on image information fusion. This system performs better than traditional methods, which can present performance problems when applied in real time.

It is also worth noting that the development of efficient solutions using simple equipment, such as those presented in [54] and [73], is very interesting for VR applications. It developed a 3D eye-gaze capture system [54] that can capture head poses and facial expression deformation. This real-time system, which demonstrated robustness and accuracy in several situations, was built using a single **red, green, and blue (RGB)** camera.

However, a limitation of some AI-based systems is their dependence on the dataset [57]. Additionally, some systems, such as those presented by [56], do not perform well when applied to scenarios different from the one on which they were trained.

Moreover, another limitation is that some developed systems, such as [54], present poor results in specific situations. The work of [69] developed a real-time hand-tracking system. However, the system performs poorly when dealing with uncommon hand viewpoints, and the developed architecture does not support hand-hand and hand-object interactions.

Some applications can have high computational costs. For example, the work of [57] developed a system that synthesizes a 4D light field from a simple RGB image. However, the system requires a large amount of GPU memory owing to the large size of the light fields.

It was observed that, in some papers, the main advantages are high precision of algorithms [175] and the best efficiency [185]. The main limitation is the high cost [177, 186].

The evaluations of [90] and [96] had low cost and high efficiency, although they first presented inaccurate depth estimation in the reflected region (car window). According to [91] great recognition accuracy was achieved, but blurry images and other features were not listed for analysis. The paper [94] offered a less stressful experience; however, the paper of [95] simplified the network and improved performance; in contrast, the training process became slower. In a study conducted by [96] risks during experiments decreased and the work of [107] had great adaptability. Finally, the studies described in [104] and [106] achieved high accuracy; scenario interactivity was greatly improved in accord [110] and the study by Li and Wu [111] improved the efficiency of data usage.

Visual esthetics significantly improved; however, the first one did not work in a specific group of objects and the other three increased the amount of processing needed [150, 161, 166, 170]. On the other hand, the studies of [155] and [163] had reduced computational processing, but the CNN used in the work [163] was incapable of maintaining the visual performance of state-of-the-art systems.

Hand tracking developed in [165] and [168] has the advantages of low cost, noncontact, and convenience compared to glove-based methods, although heavy edge noise and self-occlusion often cause matching failure. The works of [108], [169], and [172] are important for future development, but they are not yet ready for real-world usage.

Even with the advances made in AI technologies that employ VR, limitations in their applications can still be observed. As an example of this occurrence, it was observed that in the studies of [47] and [48], the topic of information security is a factor to be analyzed because systems that use AI and VR generally use cloud storage devices to allocate and transfer information.

Similarly, the works of [80] and [81] noted that the concern and difficulty of working with VR technology is related to the use of these techniques, who demonstrate side effects (mainly nausea) resulting from exposure to devices. The studies of [82] and [124] have disadvantages in terms of understanding and representing the depth of the images and models studied.

The studies of [80] and [81] used the works of [46], [52], and [78] to address the limitations presented above, bringing reasonable advantages to be applied to VR technology by obtaining a forecast of nausea cybernetic and reduction of the impact on users. In addition to making the interaction/user experience more realistic and intuitive through design optimization.

RQ4: How can AI contribute to new trends and opportunities for VR-based applications?

According to [20], the integration of AI and VR for human-machine interactive devices has a significant effect on the overall quality of service, leading to customer satisfaction and loyalty. It was reported, according to the work of [30] a combination of technology and education of AI and VR; that is, humans and systems form a world of integrated digital learning.

Furthermore, to address this question, we inquire into various studies [205], [206], [212], [214], and [215]. Researchers [205], [206], [212], and [215] presented different approaches for human pose estimation and reenactment, one of the core elements of VR technology, all of which used novel AI integration techniques to achieve this goal. In another example, [214] applied a novel pose formulation technique to create virtual user-environment interactions with this geometry, a concept that has inherent usefulness in VR development.

Artificial intelligence was used to dynamically allocate furniture and other elements from the 3D scene into a dynamic scene [229]. It is concluded that the use of these techniques allowed a better use of the 3D environment, with the arrangement of elements starting from an environment with only walls and floors.

Some studies have shown that AI can contribute by performing object recognition and image processing [175, 176, 182, 183, 186–189, 191, 192], which can be used in several different ways.

Additionally, some technologies presented AI use to create more efficient and simple applications. Consequently, VR-based applications are less complicated, more accessible, and cheaper. For example, [73] showed that the gesture recognition system is highly accurate, but does not require cameras or any other external optical sensor.

Although the technology presented needs to be improved before it can be used in the "real world," it is an example of a system that can be very useful in making VR applications more accessible and simple to implement.

Moreover, several studies have analyzed methods that use AI to overcome traditional techniques in terms of both performance and accuracy. For example, in [58] and [67], as previously mentioned, the proposed methods showed superior performance in relation to other commonly applied technologies.

The adoption of portable devices such as smartwatches that incorporate a growing set of health sensors will open additional opportunities for the personalization of autonomous vehicles [94]. AI also allows the design of smarter devices to complete complex chemical experiments [96]. It can be extended to solve the problem of continuous sign language recognition for Arabic and other languages [98].

In the future, smart investment will inevitably spread to several financial institutions; in that sense, AI can also be used for the efficiency analysis of other smart investment products [101]. Machine learning and 5G have a lot of room to improve together as a discipline [108]. It can also help develop models that will continue to play and recognize emotions successfully, even when one or more modalities are absent [114]. Finally, AI can contribute to the construction of a multimodal emotion recognition system in real time using deep architectures [114].

Additionally, the results presented [149], [158], [165], and [168] are relevant for developing a stable and reliable hand controller for VR systems, which will make these devices more intuitive to users. The papers [150] and [163] reduced the amount of computational processing required, making it less expensive. Finally, the main outcomes are in the visual field, producing more realistic images and increasing user immersion [152, 161, 155, 166, 170].

AI contributes to the applications of VR in the health field by promoting greater efficiency and precision in surgical operations, in addition to allowing for the evaluation of the effective conditions of rehabilitation of VR-treated patients [45, 53].

The studies [81], [85], [86], and [89] are trends because they introduce technological models that outperform the previous generation in terms of cybersickness, which can be used to understand in a deeper level the nausea and to predict them; an efficiency of about 82.83% accuracy of the dataset analyzed and the possibility of a five-minute step to predict motion sickness; and finally, the ability to recommend a custom image to different users in this sense.

Table 5 shows in brief how AI provides new trends and opportunities in the development of VR-based applications. The first column presents new trends and opportunities to expand VR-based applications considering AI; the second column classifies the research and development fields of the VR-based applications, and the last one the related references.

RQ5: How can AI and VR help on intelligent manufacturing or logistics?

According to [20], these tools increase the degree of customer satisfaction in establishments such as hotels and restaurants, so they can become essential for the future and development of logistics in these establishments. Because it is an industrial application, the study of [28] demonstrates how the use of VR along with intelligent robotic applications can assist in the preventive detection of potential failures and the maintenance of certain industrial processes.

In line with previous studies ([195], [198], and [204]), the use of machine learning along with image data processing methods has been analyzed in those studies. These methods have important applications in logistics, as big data has become an integral part of it for companies. Such methods may also be important for manufacturing, as they can be applied along with digital twins to effectively develop a good taking advantage of data. The work of [228] showed that integration allows a safe environment for testing with VR technology and more accurate predictions.

Papers that did not have a specific application in the manufacturing and logistics sectors were analyzed. However, based on the above-mentioned paper [69], the developed hand-track technology can be very useful in several VR applications. Here, a hand-tracking technology that leaves

Table 5. New Trends and Opportunities to Expand VR-based Applications using Artificial Intelligence

New trends and opportunities	Research and development fields	References
Improve the quality of service, leading to customer satisfaction and loyalty through human-machine interactive devices.	Services	[20]
The benefits of an integrated digital learning using humans and AI-VR systems.	Education	[30]
Contribute by promoting greater efficiency and precision in surgical operations, in addition to allowing for the evaluation of the effective conditions of rehabilitation of VR-treated patients.	Health	[45, 53]
Develop techniques of gesture recognition based on image information fusion in virtual reality with the use of artificial intelligence to overcome in terms of both performance and accuracy.	Computer Graphics	[58, 67]
Create applications in a way efficient, more accessible, highly accurate, and cheaper to the gesture recognition systems.	Manufacturing Industry	[73]
Recommend a customized image to different users due the cybersickness like nausea.	Logistics	[81, 85, 86, 89]
Enable to set the portable devices, such as smartwatches that incorporate a growing set of health sensors.	Health	[94]
Design smarter devices to evaluate complex chemical experiments.	Chemistry	[96]
Solve the problem of sign language recognition for Arabic and other languages.	Education	[98]
Evaluate in an efficient way the smart investment products.	Economy	[101]
Improve the integration of machine learning and 5G.	Telecommunication	[108]
Contribute to the construction of a multimodal emotion recognition system in real time.	Health	[114]
Develop a stable and reliable hand controller for VR systems, which will make these devices more intuitive to users.	Hardware Industry	[149, 158, 165, 168]
Reduce the amount of computational processing required, making it less expensive.	Hardware Industry	[150, 163]
Generate more realistic images and increase user immersion.	Software Industry	[152, 161, 155, 166, 170].
Contribute by performing object recognition and image processing, which can be used in several different ways.	Health/Computer Graphics	[175, 176, 182, 183, 186–189, 191, 192]
Present different approaches for human pose estimation and reenactment, one of the core elements of VR technology.	Software Industry/Logistics	[205, 206, 212, 214, 215].
Allow a better use of the 3D environment, with the arrangement of elements starting from a simple environment.	Software Industry	[229]

hands free is interesting, for example, to train the handling of industrial equipment. It can be observed that this technology, even though it is not developed directly for a specific application, can be very useful in the manufacturing sector.

Additionally, the paper [73] presented a hand pose capture technology that, when combined with a hand-tracking system, can also be very useful for controlling VR applications. In addition to training, the use of technologies such as this is essential for applications where the user needs to control industrial or logistics processes. In other words, this shows the potential impact of AI and VR technologies on the sectors mentioned.

The work of [65] presented a transportation planning decision support system developed using AI techniques. Such technologies can make a significant contribution to the logistics sector, especially in the planning of transportation systems. As shown in other studies, AI and VR can help with the quality control of materials and products and ensure better use of materials [173].

AI and VR can help improve the level of safety and promote road traffic [90, 91]. Most image classification algorithms focus on maximizing the percentage of correct rates, which have a deficiency in those images from the minority categories are related to being incorrectly classified as dominant categories. AI with VR contributes to solving this challenge [93]. In the growing field of intelligent **autonomous vehicles (AVs)**, AI and VR can help conduct a much less stressful experience, despite the increased cognitive load [94].

Recently, for classifying hyperspectral images, methods based on deep learning have shown promising performance. However, some factors make this training process time-consuming and have restricted its application. Therefore, [95] was proposed an approach using AI and VR to solve this problem, further improving the classification accuracy. This is also why the model developed by authors [97] can generate a more powerful resource expression with less. AI can also help minimize the energy consumption of all **user equipment (UE)**, jointly optimizing the positions of GVs and UAVs, user association, and resource allocation in real time, considering the dynamic environment [99].

In the countryside, work is often accompanied by tight schedules, which tend to strain the shoulder muscles owing to high intensity. To address these problems, a method for steering control of the tractor assistant was proposed [100], based on the human-machine interface, using **electroencephalographic (EEG)** signals. Waiting for easy access to smartphones, the past few years have witnessed a growing interest in the use of mobile phones as detection platforms and vehicle detection. AI can help build an efficient model for detecting vehicle driving using smartphones [106].

The systems built in the papers [153], [156], and [157] can be used to recognize images automatically, which can be useful in logistics and identifying products or people. Additionally, in shipping [148], can be used to help drivers [162], detect far-scale pedestrians in camera images [148], and rating vehicle-steering patterns [162]. However, the work of [164] developed a shop floor's digital twin, converging physical and virtual space, which increases management efficiency.

AI/VR can assist in the manufacturing process to improve the stages of industrial product development, in addition to making factories more efficient and smarter [43]. On the other hand, [46] developed a widely useful system in machine learning to transmit behavioral knowledge to welding robots, later promoting, based on the information collected, the possibility of training less experienced welders to obtain better results in this action. Finally, in relation to [52], this work presents an analysis of the use of **human-robot interaction (HRI)** to allow an adequate understanding of human-robot interaction in manufacturing industries that aims at a more intuitive interaction and with clear and concise feedback from processes.

The introduction of AI and VR technology can help intelligent manufacturing in ways such as: development of intelligent robotic applications, digital twins, quality control of materials and products, human-robot interaction, recognizing continuous using hand pose capture technology

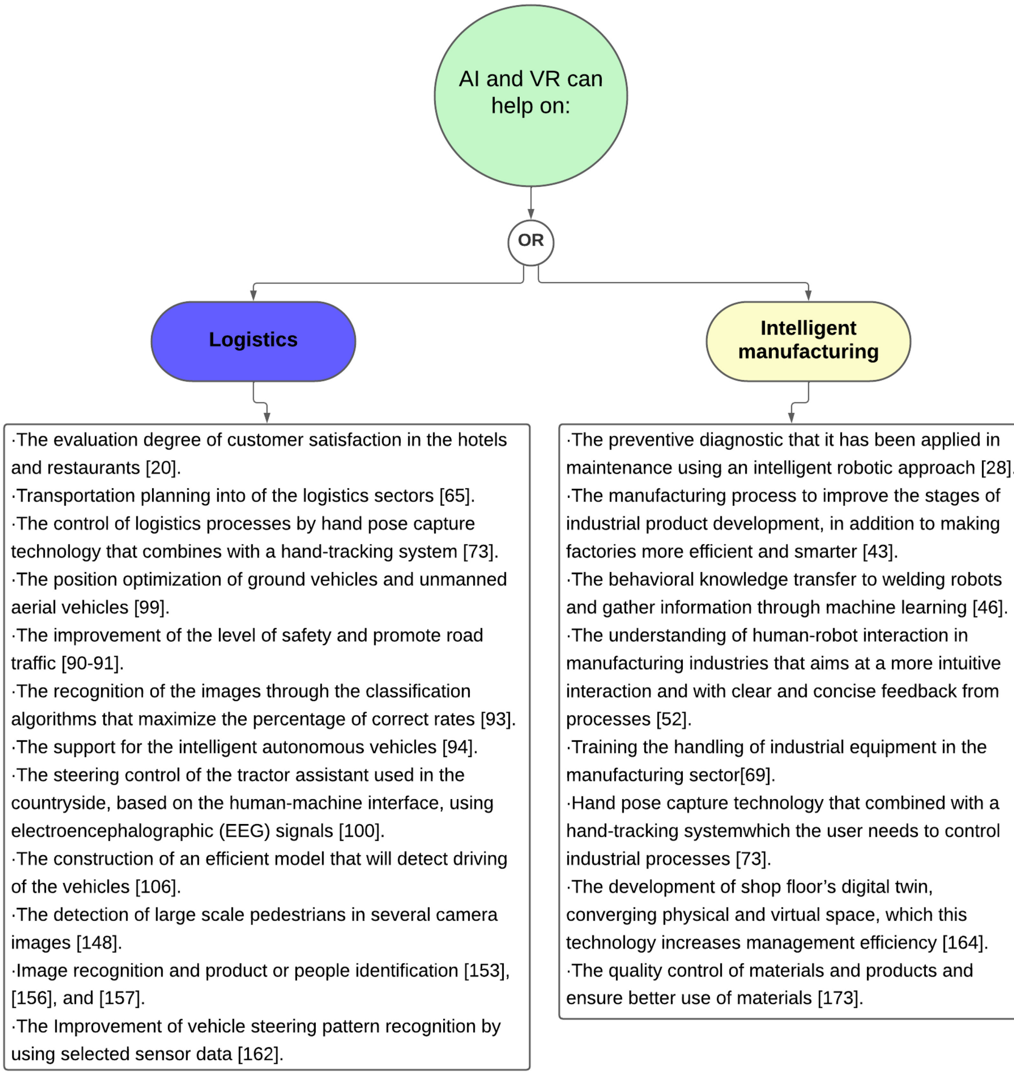

Fig. 3. The application of AI and VR technology in the industrial sector and logistic.

combined with a hand-tracking system, and improvement in the training of new employees. Already in logistics, we can refer such as recognizing of products or people by image data processing, planning of transportation, logistics processes, training in the logistics area, contentment of customers in hotels and restaurants, and optimizing the positions of ground vehicles and unmanned aerial vehicles. In short, the application of AI and VR technology in the industrial sector and logistics is shown in Figure 3.

5 CONCLUSION

In this paper, we present a literature review of the contributions of AI in VR applications using 178 applied papers. The findings in the literature presented the contributions of new trends, opportunities, applications, and potential benefits of AI in VR. The results showed that systematic literature review can address the researchers who are interested in the methods of AI in VR.

From the results, we observe that machine learning is the most applied AI scientific technique in VR applications. In this scientific procedure, the subfields are neural network, deep learning, and fuzzy logic. However, intelligent robotic applications are also necessary in this procedure.

The findings revealed several fields of applications in the real world that employ AI in VR, such as teleconferencing, human-robot interaction, emotion interaction and behavior recognition, education, agriculture, transport and tourist services, image data extraction, 3D image reconstruction, cognitive load measurement, and health.

The results also highlight the fields that use AI in VR as human facial expressions to help treat children with autism, botany for identifying plant species, and controlling an MAV used in commercial aerial surveillance and disaster relief operations. Additionally, we can mention construction planning, chemical industry, Arabic sign language, smart investment, design of layout, energy transmission and distribution, and ground vehicle and unmanned aerial vehicle positions.

The results show that when AI methods are used in VR applications, the main advantages are high efficiency and precision of algorithms. The potential to improve human-machine interaction, especially in situations involving intelligent robotic technologies, was also mentioned as a benefit. The findings also provide a reference for the effective use of data relayed by external sources and the use of datasets to adapt to different contexts.

However, the main limitations are the high computational cost and the dependence on the dataset. This subordination to data implies that some applications do not perform well when applied to scenarios different from the ones on which they were trained. Some papers have shown limitations in capturing the initial data and information security systems. These systems that use AI and VR generally use cloud storage devices to allocate and transfer information. Additionally, a real-time hand-tracking system performed poorly when dealing with uncommon hand viewpoints, and the developed architecture did not support hand-hand and hand-object interactions.

The studies reviewed in this work show that the combination of AI and VR contributes to new trends and opportunities for human-machine interactive devices, leading to customer satisfaction and loyalty. Moreover, this combination contributes to the world of integrated digital learning, object recognition, and image processing, which can be used in several ways. Additionally, portable devices such as smartwatches with health sensors and smart devices to complete complex chemical experiments will provide additional opportunities for personalized devices. Finally, AI and VR contribute to the health sector by increasing the efficiency and precision of surgical operations, as well as allowing for the rehabilitation of treated patients.

AI and VR technologies can help in intelligent manufacturing to train the handling of industrial equipment, quality control of materials and products, and minimization of the energy consumption of equipment. They reduce stress in the company and make factories more efficient and smarter. Moreover, big data has become an integral part of companies. There are methods for evaluating these data, which are more important in manufacturing. It can be applied along with a digital twin to effectively develop a collect of the data from various sources as for example, manufacturing data and operational data. Technologies such as AI and VR can make a relevant contribution to the logistics sector, especially when it comes to the planning of transportation systems and can be useful for identifying products or people. Additionally, they improve the level of safety, promote the work of road traffic, and help conduct a much less stressful experience.

Besides manufacturing and logistics in the findings of paper distribution, education was the economic sector most present, followed by health and telecommunication, among others. The percentages of the paper distribution according to the economic sectors were: education, manufacturing, logistics, health and telecommunication, 25.3%, 22.5%, 10.7%, 9.0%, 5.1%, respectively. We also observe in results, in terms of percentage that the fields of research in highlights were:

learning (41.0%), health (17.4%), transport services (7.3%), environment (4.5%), wireless communication (2.8%), mining industry (2.2%), and civil construction (2.2%), and so on.

In general, this review underlined the most well-known challenges of the IA fields: the challenge of building large datasets; results assessed only on benchmark datasets; great dependency on computers with high processing power; scenario fails in some extent when switching to a particular application; and small datasets limits generalization power.

We emphasize that the scope of keywords adopted and chosen, as well as the restriction on use with thesis, monographs, books, technical and reports, and theoretical papers, were the limitations of our work. Thus, if other keywords and documents are adopted, the findings may reveal different results.

As previously discussed, some trends and opportunities were observed in the analyzed papers. In future work, a new structured review needs to focus on finding new VR applications, which will combine the novel technologies of AI. This review can identify new challenges, trends, advantages, and help with other intelligent systems different from manufacturing and logistics, such as education, health, tourism, chemistry, and business.

Other future research can be conducted with more emphasis on AR, since it is deeply related to VR, but it was not explored directly in this work. Finally, a systematic review in the future can be conducted in VEs with an AI agent, which may react to the user's emotional expressions. Thus, it could be a powerful tool for many applications ranging from gaming to psychology.

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