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Chapter 5

Human-centric artificial intelligence in industry 5.0: Enhancing human interaction and collaborative applications

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Abstract: The fifth industrial revolution - or Industry 5.0 - likely see human-centric artificial intelligence (AI) revolutionize by literally putting humans in contact and integrated with AI advancements. While its predecessor, Industry 4.0, cantered on automation and productivity by integrating cyber-physical systems and the Internet of Things (IoT), Industry 5.0 focuses on the cooperative connection between human workers and AI systems. This study investigates the recent and well-established uses of humanistic AI and provides a deeper insight into the possibilities of improving various sectors of the industry. Use cases range from making cobots even more collaborative by making them totally safe to work alongside humans, to having AI-assisted decision-making that further enables human operators real time with smarter decision making and problem solving. The sophisticated natural language processing (NLP) and computer vision technologies create an intuitive human-machine interfaces to communicate and interact without any hindrance. They are even experimenting with AI enabled training and simulation tools, reinforcing and reskilling the current affected workforce to meet the developing and dynamically larger requirements of Industry 5.0. By moving towards ethical AI principles, we assure that AI implementations keep human values and societal benefits at the core and mitigate issues on privacy, bias, and transparency. This research has implications for human-centric AI, reaffirming the value of building an integrated and resilient industrial ecosystem that capitalizes on the collective strengths of humans and intelligent systems to deliver innovation, resilience, and growth for the economy.

Keywords: Industry 5.0, Human-centric, Artificial intelligence, Machine learning, Deep learning, Internet of things

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5.1 Introduction

The recent years Industry 5.0 era has come to change some points on the path of industrial development (Xu et al., 2021). The integration of advanced technologies with human-cantered methods is longer a future solution. While Industry 4.0 was concerned with automation and the Internet of Things (IoT), Industry 5.0 is about partnership between human and machines in the manufacturing process that enables a new level of productivity, creativity and satisfaction at work (Leng et al., 2022; Huang et al., 2022; Paramesha et al., 2024a). At the core of this new era of thinking is the principle of being human-centric in the deployment and design of AI system, which places the requirements, the wishes and the welfare of human beings at the centre of the system potion. With the unprecedented evolution of AI technologies, machines are now able to perform exceptionally accurate and efficient jobs of an intricate and complex nature (Maddikunta, et al., 2022; Akundi et al., 2022). This integration of technology with industry often brings fears of job loss, ethical dilemmas and the decay of human skills. Human-Centric AI, on the other hand, hopes to overcome these shortfalls by positioning machines in the service of humanity, deploying AI to supplement - rather than usurp - human performance (Tiwari et al., 2022; Golovianko et al., 2023; Paramesha et al., 2024b). It does so in ways that both maintain the irreplaceable value of human workers and elevate their tasks through intelligent assistance and collaboration.

In Industry 5.0, AI systems can give the ability to perceive the emotions, desires, and will of man, interacting with man more purely and intuitively (Xu et al., 2021; Huang et al., 2022; Rane et al., 2024a). This transition demands the creation of transparent, interpretable and value-aligned AI models. With a human-cantered approach, organizations can harness AI for more inclusive and dynamic workplaces, in which technology is merely a tool enabling human capabilities rather than a source of competition. The present study carries out an extensive review of the extant literature on human-centric AI in the context of Industry 5.0, provides an overview of the applications of human-centric AI and investigates what kinds of AI technologies can be applied through human factors.

Contributions:

1) Reviews the extant work in human-centered AI to encode the types of themes, trends, and gaps in the literature.
2) Studies keywords which are prominent and cooccur in the domain, and gives a complex view mapping the research landscape.
3) Applies cluster analysis to extract key research clusters, reveal the internal structure and relationship of the literature.

5.2 Methodology

The methodology of this research has been structured on the basis of literature review, keyword analysis, co-occurrence analysis, cluster analysis etc. Searching academic articles, conference papers, and industry reports was performed by using the keywords through IEEE Xplore, Google Scholar, and Scopus databases for collecting relevant literature for the research review. The central theme of this review was to identify the primary concepts, patterns and the lacunae in the literature on human centric AI in the context of Industry 5.0. During the keyword analysis, the literature review was done, and keywords or phrases on human-centric AI and Industry 5.0 were searched. These keywords were then used to find the occurrences and within-text relationships of the keywords. A co-occurrence analysis was performed to identify relationships among these keywords and established the key research themes as well as emerging categories within the domain of interest. The related keywords and themes were grouped into different clusters for performing a cluster analysis. The analysis helped to identify the core research areas and interdisciplinary relations in the area of human-centric AI in Industry 5.0

5.3 Results and discussions

Co-occurrence and cluster analysis of the keywords

The network diagram (Fig. 5.1) shows the various keywords of human-centric artificial intelligence (AI) in Industry 5.0 coexist in interconnectedness that stimulates a great deal of potential innovation that underlies the whole system. It uses the nodes to represent the individual keywords and the edges to show the connection between the keywords based on their co-occurrence. Size of the nodes indicates the frequency at which each term appears and the presence of associations between two terms are illustrated by the various clusters in the colours they are in. Cantered on Industry 5.0, the green cluster introduces the implementation of cutting-edge technologies and the development of an industrial environment geared towards human wants and needs. One of the key words in this group is the term words "human-cantered," which underscores the importance of keeping human needs, preferences, and interactions at the front of industrial processes. Human-cantered design is human centric. The immoderate attention to the joy or happiness and health or well-being of the individual. The term human selective intervention is akin to human-centered notions, such as human factors, ergonomics, or the human-robot collaboration. It serves to impress upon the value of making the manufacturing process efficient. It is revealed when words conjoining when the words as assembly, production system and manufacturing are used. This is the cluster where robots and their collaborative counterparts, cobots, become absolutely critical. Their main goal is to collaborate with humans to improve efficiency and ensure safety. In fact, the use of innovative technologies such as digital twin and augmented reality combined with equipment data can greatly improve equipment maintenance and even decision-making levels, needing interactions that were previously impossible with machines. This cluster is about transitioning to a sustainable, collaborative industry where the healthiness and productivity of the individual in focus.

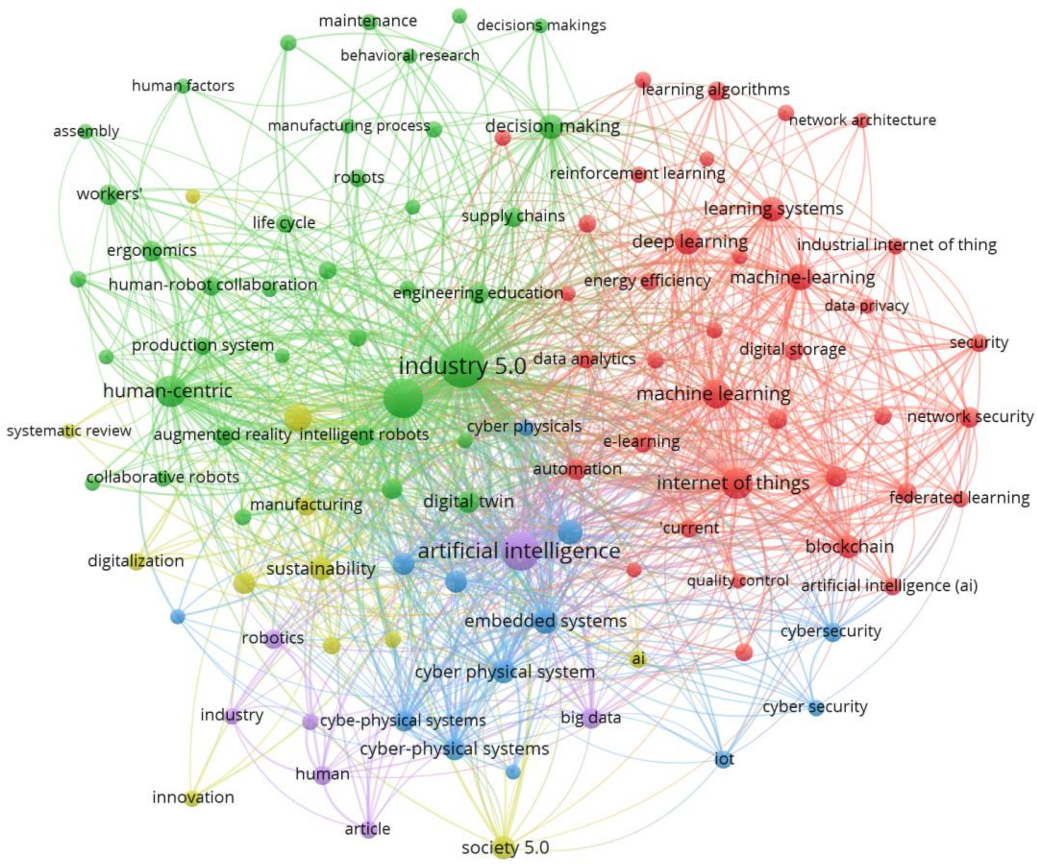

Fig. 5.1 Co-occurrence analysis of the keywords in literature

The red cluster focus on the nitty-gritty and analysis parts of Industry 5.0, which is underpinned by ML and DL, respectively. Indicatively advanced algorithms and learning systems for processing big data and making better-decisions are the concepts behind terms such as "machine learning" or "deep learning". Gaining knowledge and evolving in response requires an understanding of learning algorithms, like reinforcement learning. IoT is the important concept of all that greatly allows the devices and systems to interoperate in real time and are subject to their form of a connection. This theme ties neatly back to terms such as digital storage, data confidentiality and cyber security. Brand trust is kept by blockchain technology that ensures the integrity and security of data in IoT and other interconnected systems. In doing so, it promotes trust in digitised systems through secure data transactions. Originally conceived to swoop into the ethereal world of some Industry 5.0 fairy-tale, this cluster likes to tout itself as the epitome of utilizing bleeding-edge computational methods to birth intelligent and autonomous systems.

In the blue cluster, AI and embedded systems are focused. This relationship is the cornerstone in becoming an autonomous and responsible technology compass. AI is a broad topic that covers a great deal of diversity in applications and technologies where machines imitate human intelligence. This term is related with similar concepts such as machine learning, deep learning and big data etc. The success of AI in physical dynamic environments based on embedded systems and cyber-physical systems. The power of these systems is vital, as it helps in the processing of real-time data, incorporating the interaction of the digital and the physical world. As AI and embedded systems are being used more and more, it is also important to put a high emphasis in cybersecurity. The above-described idea is deeply related with network security as well as the federated learning solution. This activity is very essential to secure our data and system from incessant cyber threats. This cluster promotes secure and intelligent technologies in Industry 5.0, utilizing AI within physical systems.

The yellow cluster explores the societal components of Industry 5.0 and drills into how society and sustainability are affected by these new technologies. Society 5.0 represents a delightful concept based on evolving human culture and digital infrastructure in order to change our way of doing the things so that it covert all spectrum of life into digital operations from daily life to Industry and society all these changes will bring more convenience in life and support to tackle essential challenges. The cluster reminds us of the need for sustainability; it pays more attention, we hope, for environmental-friendly and sustainable practices in the industries. It was with this idea that the concept of innovation, of digitalization, of reviewing everything in detail were so intertwined. Meticulous work carried out by human factor researchers and behavioural scientists concluded the importance of understanding human behaviour and ergonomics. This insight is also important when designing easy-to-use and high-performance systems. Cluster on Industry 5.0 incorporating implications of society- This cluster entails the societal fabric in the advent of Industry 5.0, with universal integration of technology given the requirements of social and environment.

This analysis of co-occurrence exposes the complex interactions amongst different keywords - demonstrating how themes and technologies are interconnected and act together to affect the industry 5.0. This emphasizes the importance of Industry 5.0 concepts and AI as we demonstrate the connecting linkages within the field and their broader impact across numerous sectors. The fact that many clusters are interconnected indicate thematical convergence and interdependencies. A perfect example is the inherent link between AI and Machine Learning - a bridge between the tech-spec realm and the humanized side of it. This link shows one way that they can expand computational capabilities, but also enable significantly new kinds of human interactions. The changes such as digital twin, augmented reality, and blockchain among many others are rising as the most important technological advancement and emerging trends, the network is witnessing. These advances by themselves are indicative of the increasing role they play in Industry 5.0.

Components and interactions in human-robot collaboration systems

The information about components and their interactions in a better context of human-robot collaboration are given Fig. 5.2. It also features cognitive work analysis, gesture recognition, and virtual reality inside the Human-Robot Collaboration component to enhance the synergy between humans and robots; it also shows contextual visual feedback to improve interaction based on brain signals under the Brain-Machine Interfaces component. The other key technology components in this architecture will be cyber-physical systems, which are instrumental in integrating technology with societal systems, and artificial intelligence, which will be applied with advanced AI techniques. The figure demonstrates equal or much-needed prominence for human-machine interfaces and human motion prediction to enable intuitive and efficient interactions. Finally, quality control will guarantee that standards are maintained in collaborative processes, especially in assembly. It means a comprehensive framework underpinning how various technologies and methodologies interlink to advance human-robot collaboration toward creating safer, more efficient, and more effective collaborative environments.

Emerging technologies and trends in enhancing human-machine collaboration

The use of complex AI and ML algorithms was one of the greatest progresses in human-machine collaborations (Xu et al., 2021; Huang et al., 2022; Rane et al., 2024b). Machines that are fed on data, the data helps the machine to learn, adapt and make decisions with little human dependence of supervision (Maddikunta, et al., 2022; Akundi et al., 2022).

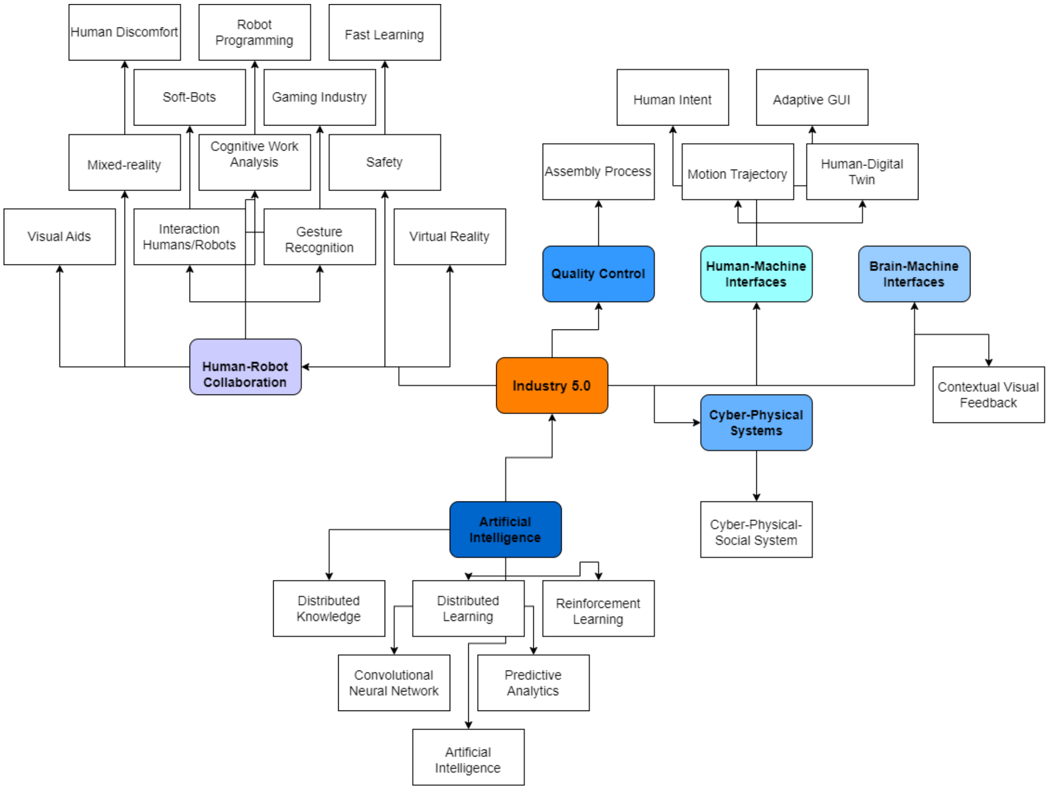

Fig. 5.2 Components and Interactions in Human-Robot Collaboration Systems

In the manufacturing industry, for example, predictive maintenance systems can gain insights from machinery data powered by AI and forecast machinery failures taken place in the near future, in order to minimize downtime and maximize efficiency (Van Oudenhoven et al., 2023; Maddikunta et al., 2022; Khan et al., 2023; Paramesha et al., 2024c). Likewise, in healthcare, AI algorithms can help doctors to diagnose diseases by analysing medical images and patient data quicker and more accurately compared to traditional way (Gomathi et al., 2023; Maddikunta et al., 2022; Rane et al., 2024c). Another transformational technology enabling man-machine collaboration is robots (Raffik et al., 2023; Maddikunta, et al., 2022; Zafar et al., 2024; Rane et al., 2024d). The best example is the modern robots which are equipped with state-of-the-art sensors, actuators, and AI capabilities that let them detect the world and collaborate with humans to perform tasks that are beyond what the best robot or the best human could do on their own (Maddikunta, et al., 2022; Zafar et al., 2024; Paramesha et al., 2024d). Cobots or collaborative robots are intended to work alongside humans in a safe manner doing like packing, assembly or inspections. By growing businesses, automaton is increasing not just productivity but also safety in workplace. In addition, integration of AI with robotics are developing intuitive and adaptive robotic systems in which these systems learn from human actions and can work in dynamic environments. Fig. 5.3 shows the emerging technologies and trends in enhancing human-machine collaboration.

Table 5.1 Emerging trends, applications and future trends in enhancing human-machine collaboration

References	**Trend**	**Applications**	**Challenges**	**Future Trends**
Chandel, & Sharma, 2021; Maddikunta et al., 2022	Artificial Intelligence (AI)	Virtual assistants, predictive analytics, decision support	Ethical concerns, bias in algorithms, high implementation costs	Increased integration in all sectors, development of ethical AI frameworks
Taj, & Zaman, 2022; Nguyen, & Tran, 2023	Machine Learning (ML)	Personalization, fraud detection, predictive maintenance	Data quality and privacy issues, algorithm transparency, skill gaps	Expansion in predictive analytics, advancement in unsupervised learning
Mah et al., 2022; Rane, 2023; Davila-Gonzalez, & Martin, 2024	Natural Language Processing (NLP)	Chatbots, language translation, sentiment analysis	Understanding context and nuance, multilingual processing, privacy concerns	Improvement in contextual understanding, real-time language translation capabilities
Paschek et al., 2022 Raja Santhi, & Muthuswamy, 2023	Robotic Process Automation (RPA)	Data entry, invoice processing, customer service	Process complexity, scalability issues, integration with existing systems	Integration with AI for intelligent automation, expansion to more complex processes
Fernández-Caramés, & Fraga-Lamas, 2024; Carrança et al., 2023; Zafar et al., 2024	Augmented Reality (AR)	Training, remote assistance, product visualization	Hardware limitations, user acceptance, data privacy concerns	Development of more affordable and accessible AR devices, enhanced user experiences

Fernández-Caramés, & Fraga-Lamas, 2024; Alojaiman, 2023)	Virtual Reality (VR)	Training, simulation, entertainment	Motion sickness, high costs of equipment, content creation challenges	Adoption in more sectors like healthcare and real estate, development of social VR platforms
Zafar et al., 2024; Husár et al., 2024	Mixed Reality (MR)	Design, prototyping, collaborative projects	High cost of development, limited content availability, technical challenges	Increasing use in industrial design and healthcare, advancements in MR technology for more seamless integration
Chander et al., 2022; Zong et al., 2021; Özdemir, & Hekim, 2018; Aslam et al., 2020	Internet of Things (IoT)	Smart homes, industrial automation, healthcare monitoring	Security vulnerabilities, data privacy issues, interoperability	Growth in smart city initiatives, more robust security solutions for IoT devices
Leng et al., 2022; Wang et al., 2023	Blockchain Technology	Supply chain management, secure transactions, identity verification	Scalability issues, regulatory concerns, energy consumption	Wider adoption in non-financial sectors, development of energy-efficient blockchain solutions
Anbalagan et al., 2023; Chander, et al., 2022; Fraga-Lamas et al., 2021	Edge Computing	Autonomous vehicles, smart grids, IoT devices	Security risks, data management complexity, need for robust infrastructure	Growth in real-time processing capabilities, expansion in edge AI technologies
Adel, 2023; Kasinathan, et al., 2022	5G Technology	IoT, smart cities, autonomous vehicles	Infrastructure costs, regulatory hurdles, security concerns	Expansion in IoT and smart city applications, further development in 6G research

Nguyen, & Tran, 2023; Coşgun, et al., 2023	Wearable Technology	Health monitoring, augmented reality interfaces, fitness tracking	Privacy concerns, battery life limitations, user compliance	Advancements in health monitoring capabilities, integration with AI for personalized insights
Raffik et al., 2023; Maddikunta, et al., 2022; Zafar et al., (2024)	Collaborative Robots (Cobots)	Manufacturing, healthcare, logistics	Safety concerns, integration with human workflows, high initial costs	Development of more intuitive and safer cobots, increasing adoption in small and midsize enterprises
Lv 2023; Zafar et al., (2024); Mazumder et al., 2023	Digital Twins	Manufacturing, urban planning, healthcare	Data accuracy, integration complexity, high costs of implementation	Increased use in smart cities and infrastructure, advancements in real-time data integration

The advent of Internet of Things (IoT) is also significant, promoting higher efficiency in human-machine collaboration (Chander et al., 2022; Zong et al., 2021; Özdemir, & Hekim, 2018). IoT devices are sensor-laden and internet-connected, enabling the collection and real-time transmission of data (Aslam et al., 2020). This connectivity becomes the spine of how we transmit information between machines and humans, incorporating a level of decision-making and automation. IoT sensors can be used to monitor machine performance and ambient conditions in real time in smart factories (Özdemir, & Hekim, 2018; Zong et al., 2021), for example, and give human operators real-time insights least human. This even results in more effective and responsive systems as integrating IoT with AI and ML to analyse enormous chunks of data only gets better with more unification. The tools to enhance human-machine interaction can be Augmented Reality (AR) and Virtual Reality (VR), poised to become the next computer platform and the next big technology (Fernández-Caramés, & Fraga-Lamas, 2024; Carrança et al., 2023; Alojaiman, 2023; Rane et al., 2024e). AR lays digital information on the actual physical world, giving users AR allows users to experience, see, and analyse data. In industry, AR can help workers in assembling or manufacturing by showing assembly instructions, visualizing possible problem, or remote collaboration with experts. On the other hand, VR does create an experience in a full virtual environment that could be used for training, simulation or design. In healthcare, VR is being used for simulating surgery and rehabilitation so that the practice is effective while also ensuring no physical harm. These technologies not only helped improve human-machine collaboration to a great extent but also aided in better training and skill development. Table 5.1 shows the emerging trends, applications and future trends in enhancing human-machine collaboration.

NLP and conversational AI have caused a switch in the interaction between man and machines moving from more tedious arrangements to an intuitive and more natural communication (Mah et al., 2022; Davila-Gonzalez, & Martin, 2024; Rane et al., 2024f). Advanced NLP algorithms enable machines to understand and respond to humans using natural language, providing smooth communication through voice commands, chatbots and virtual assistants (Rane, 2023). For example, in customer service, AI-powered chatbots can answer routine inquiries thereby allowing human agents to work on more complex issues. At work, virtual assistants such as IBM Watson or Google Assistant help schedule meetings, manage emails and other administrative tasks that makes us and workers as a whole more productive and reduces mental fatigue. Another rising trend, edge computing, is improving the collaboration of humans and machines by moving data processing nearer to the point of data generation (Anbalagan et al., 2023; Fraga-Lamas et al., 2021; Paramesha et al., 2024e; Rane et al., 2024g). This helps reduce latency and improves the responsiveness building AI applications which is extremely important for real-time decision making and automation. Edge computing in autonomous vehicles, for instance, will process data from sensors and cameras in near-real-time so the vehicles do not drive into obstacles. In addition to added security, this local processing power is especially useful when network connectivity is an issue; for example, in rural areas or with devices that need to operate standalone or in resource constrained environments.

This convergence of AI, robotics, IoT, AR/VR, NLP and edge computing is emerging a new collaborative paradigm like the idea of digital twins (Lv 2023). A digital twin is the virtual representation of a physical asset, process or system, which applies advanced analytics and technologies to simulate, predict and optimize performance in real-time (Zafar et al., 2024; Mazumder et al., 2023; Rane et al., 2024h). IoT-Digital twins offer immediate process insights that could occur at any given hour of manufacturing floor. They could also predict maintenance, process dysfunction and downtime, and in effect optimize operations. Digital twins in urban planning can model the effects of new infrastructure projects - a boon for decision-making and planning. AI and digital technology are having a disruptive impact on the way we learn through personalizing our learning ecosystems in education.

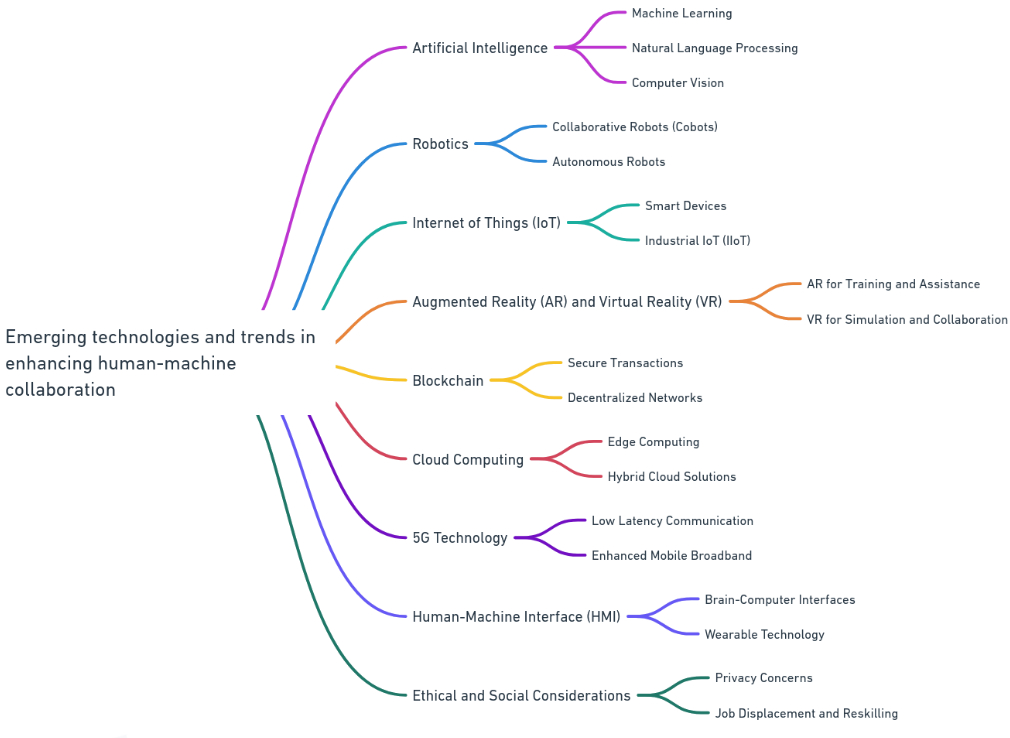

Fig. 5.3 Emerging technologies and trends in enhancing human-machine collaboration

On the other, AI tutoring systems, with the help of the large amount of data and insights they collect, can better understand the student performance and customize the instructions to serve the individual, and in the long-run improve the learning outcomes. Educators are also using this technology for creation of 3D models from scratch which students scan and the same can be experienced through AR/VR medium, so students can learn complex subjects in a fun way. The impact of these technologies is not just felt in the collaborative efforts between the teacher and the learner, they are also enabling a new type of peer-to-peer learning.

Table 5.2 details all the various elements involved in creating and interacting with a human-centric digital twin. All of these elements are important in collecting, processing, and making use of data for the construction of a comprehensive digital representation of a human user that allows advanced interaction and simulation capabilities. This table explains the interplay of technological platforms and data building up the human-centric digital twin and thus shows the sophistication and integration needed to create such advanced systems.

Table 5.2 Components and functions of human centric digital twin

Component	Description
Biological Sensors	EEG, EMG, fNIRS, and vitals measurement sensors collect biological data from brain activity, muscle activity, functional near-infrared spectroscopy, and vital signs, respectively.
Visual/Motion Sensors	Devices capturing motion data and visual information, like RGB-D cameras, VR/AR HMD trackers, and motion capture devices, empower interactions in virtual and augmented reality environments.
Direct Input	Handheld controllers and voice commands are methods of direct interaction that allow users to provide input and exercise control over devices.
Human Centric Computational Intelligence	This component ingests, processes, and analyzes human-centric data, allowing intelligent decision-making and predictive analytics.
Human Digital Twin Inputs	It caters to 3D hand pose estimation, gesture recognition, facial expressions, face recognition, natural language processing, motion prediction, brain-computer interface, and biomedical sensor data.
Human Centric Digital Twin	It provides VR/AR functionality, physics simulation, and hardware connectivity with photorealistic rendering to generate an all-inclusive digital representation of the human user.
Physical Environment	It collects information about the environment pertaining to air quality, air flow, light, and noise-level conditions to impact the user's physiological surroundings and overall experience.
Robots (Autonomous Machines)	It is equipped with onboard cameras and other listed sensors, LIDAR and infrared visions, force/torque sensors, and joint angle measurements to allow autonomous operation and interactions.

Ethical and Trustworthy AI in Industry 5.0

The use of AI in a domain like Industry 5.0 brings with it, a battery of ethical dilemmas (Vyhmeister, & Castane, 2024). At the heart of all of these, there are issues of accountability (Vyhmeister, & Castane, 2024; Wajid et al., 2022; Chander et al., 2022). As AI systems gain more autonomy; it becomes more difficult to know who to trust when debating what actions will be taken by these increasingly independent systems. In the example of a system in a factory causing an incidental, such as a robot driving by an AI engine, might struggle to assign liability, to the operator of the machine, the manufacturer, or the party that procured the software. Similarly, biases exist in AI algorithms as an ethical concern (Chander et al., 2022; Vyhmeister, & Castane, 2024; Rane et al., 2024i). Because AI systems learn from data and, if the data contains biases, the AI can produce biased decisions and results. Biased AI in an industrial context can result in discriminatory hiring policies and unfair labour treatment as well as an unjust distribution of resources. Regardless of the boundaries set, it is imperative that AI systems are trained on fair, balanced data and regularly assessed for equity. Another important ethical problem which arises is the issue of privacy (Khan et al., 2023). In Industry 5.0, AI systems receive the level data-including personal data regarding employees. The high-value data must be kept private and secured as much as possible from hacking and insider breach. To protect individual information and comply with privacy regulations, data governance frameworks need to be strengthened.

Without trust, AI in Industry 5.0 cannot ever be accepted. In the creation of AI, it is essential that we have Transparency. Explainable AI should have the ability to explain their decision why they have taken such decisions in the first place which should be understandable to humans. Stakeholders are clearly able to understand what decisions are made and based on what criteria, and in this transparency, trust can arise and stakeholders can have the certainty that this is a valid and a fair system. There is also the important requirement to secure and harden AI systems. AI systems also need to be able to act as intended in the face of cyber-attacks, and under certain conditions. This requires regular security audits, deploying high end cybersecurity, and vigilantly tracking vulnerable points on the web. Trustworthy Ethical AI governance frameworks are the key (Wajid et al., 2022; Chander et al., 2022). These guidelines should be embodied into a framework for the ethical deployment of AI, such as fairness, accountability, transparency, and privacy principles. Compliance with these guidelines helps to ensure that AI is used in a way that is beneficial to people and society.

In Industry 5.0, the redefined ethical deployment of AI must be backed by strong regulatory and legal frameworks (Akpuokwe, et al.,2024; Gerke et al., 2020). Regulations that address the rule of ethics on AI, accountability, bias, and privacy need to be established by the governments and international bodies. The source of these rules needs to be relevant with the ever-evolving speed of progress of AI, but must also be certain about what developers and end-users are welcome to experience. Industry standards and best practices also need to be established to ensure AI is implemented ethically. The ideal way forward to create those standards is through the collective process of creating and defining them with stakeholders from academia, industry, and civil society to make sure they are not only broad, but also balanced.

Challenges and barriers to human-centric AI implementation

Data privacy and security concerns

A major impediment in the use of human-centric AI tools is precisely the data privacy and security dimension (Khan et al., 2023). The system of AI itself in a human-centric design specification needs a lot of personal data, which significantly challenges privacy concerns. Finding a way that data is gathered, stored, or utilized to be kept secure so that no attacks or misuse occur is a difficult job. Data privacy is a foundational consideration and a moving target, as we operate in a world of evolving data privacy regulations such as the General Data Protection Regulation (GDPR) in Europe setting stringent data handling requirements. This drives organizations to tread cautiously with regulations that mandate heavy investments in secure data infrastructure and compliance procedures.

Bias and fairness issues

Decision making depends on whether their data was any fair/unbiased (Rajesh, 2023; Vyhmeister, & Castane, 2024). Natural AI seeks to treat people fairly and impartially-except, like most other major systems, it is susceptible to discriminatory results if the data used for training are too biased. Detect biases in available data, correct, and ensure that the inputs to algorithms are diverse and representationally spread. This will require continued work in data gathering and labelling, and in fairness of algorithms. Finally, if we are to trust AI as much as our own intuitions, the process of decision making must occur with transparency, which in complex AI models that are so effective means a final element of the barrier to trust between the machine and us.

Ethical and moral implications

AI applications are human-centric and the ethical questions about AI are consequential (Vyhmeister, & Castane, 2024; Wajid et al., 2022; Chander et al., 2022). Its ethical borders lead to moral grey areas, of how much AI should mediate in processes impacting human lives. E.g., in the healthcare field, AI can diagnose diseases, but how much should AI have a say in whether or not diseases should be treated? It is difficult to create and abide by ethical guidelines and frameworks that apply to all because people from various cultural backgrounds and other societies are brought up with different ethical values.

Human-AI interaction

The seamless interaction between human and AI systems is necessary for AI to be more human-centric (Huang et al., 2022; Maddikunta, et al., 2022). Intuitive design of user interfaces that satisfies all user needs (Akundi et al., 2022; Tiwari et al., 2022). But doing so requires us to understand human psychology and behaviour, which is quite complex and differs from person to person. In addition, coding AIs to comprehend and respond appropriately to human emotion or social cues is a massive challenge that would require advances in the countless fields of natural language processing and affective computing. The aim is that of creating AI a far more natural and valuable user-interface, yet interacting between humans and AI at this level is still in the early stages.

Technological limitations

Despite tremendous progress, there are still technical constraints that prevent truly human-cantered applications of AI. Current AI models especially deep learning models need a lot of computational power and big amounts of data to be trained and these to be present are not always possible (Jabrane, & Bousmah, 2021; Özdemir, & Hekim, 2018). Furthermore, most AI systems are non-general, which is to say that they excel at particular jobs but have trouble with the bigger picture. There is no easy path to solving these huge technological challenges that need not stop research and development even if these gaps are not crossed but will take years to catch up with the system currently in place in ways that are going to be hard to do without the AI infrastructure that now holds so much promise.

Societal and cultural barriers

This suggests human-centric AI should be social and culture context aware (ÓhÉigeartaigh et al., 2020). While something may be appropriate or effective in one culture, another culture may be offended by it. This cultural adaptability is a huge challenge because AI systems must be programmed in a way to be able to respect and comprehend cultural norms and values. Societal acceptance, moreover, significantly differs regarding AI due to the fear of job displacement, privacy intrusion, or the technology distrust of specific populations. The trust that their work will not be replaced by AI needs to originate from sharing of guidelines as well as public involvement and education.

Regulatory and legal challenges

Given the infancy of this technology, the rules of the AI use are not yet fully clear, and governments and international bodies are working to establish regulations to police the safe and ethical use of AI. The issue here is that these regulations can be quite different from one region to another, meaning that businesses managing a global network must always be aware of and comply with a constantly changing landscape. Meanwhile, the laws around the responsibility for AI-decisions, especially in fields like autonomous driving or in healthcare. This is a procedure that, again, is and will (continue to be) a complex and constantly ongoing process, as AI system must always respect all laws and regulations in pertinent jurisdictions (Akpuokwe, et al.,2024; Gerke et al., 2020).

Economic and resource constraints

Deploying human-AI centric solutions requires a lot of money because it needs investment in technology, skill and infrastructure (Korinek, & Stiglitz, 2021; Zhu et al., 2022). Some small companies, or those in low development countries, may be priced out of the market for advanced AI solutions. There is also a worldwide absence of technology savvies in the area of AI which causes many organizations to struggle with finding the right people to create and manage a human-centric AI system. Dealing with these economic and resource constraints is pivotal in accelerating widespread AI adoption.

5.4 Conclusions

Industry 5.0 is a future that is deeply saturated in human-centric AI and enhanced, augmented and collaborative interaction. This evolution focuses on the harmony between human creativity and intelligent technologies, creating a united environment that stands way beyond the boundaries demarcated by Industry 4.0. Industry 5.0 places human experiences of technology first, integrating AI systems specifically made to enhance human potential, emphasizing user experience, ethical concerns, and societal impact. The impact of AI is noticeable now more than ever with advancements in human-computer interaction tools like natural language processing, computer vision, affective computing, and more, becoming more fine-tuned and easier to interact with. These advancements permit the machines to detect and react to human emotions, postures and talking style to make the interaction more natural and human like. For example, AI-infused collaborative robots, or cobots, were created to co-work with humans in manufacturing settings, improving productivity while securing safety and ergonomics. Leveraging state-of-art sensors and ML algorithms for human understanding, these cobots can sense what humans need and adjust their work cycle, turning it into an experience. Besides, the human-centric AI in Industry 5.0, it also changing other industries such as health, education industry, and customer support. AI driven diagnostics and personalised treatment plans in healthcare, enables better patient care by providing more accurate and timely interventional care of high quality. AI-powered adaptive learning platforms deliver personalized learning experiences that suit the individual needs of the students and practice inclusive educational practices. Besides, chatbots and virtual assistants represent the most technologically advanced aid, as they use AI to carry out an empathetic, personal customer service to satisfy users, instantly. Industry 5.0, by putting human interaction and collaboration at the center stage further enhances productivity and innovation and at the same time ensure that technological advancements are disciplined by human values and societal well-being.

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