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RESEARCH AND EDUCATION FOR INDUSTRY 5.0

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Abstract:

Over the last decade, the world has seen significant technological changes characterized by complex digitization of technical and non-technical processes. All industrial revolutions to date have represented significant milestones in our lives triggering significant changes towards improvement of the quality of life, increasing safety, reliability and comfort. The current state-of-the-art in the development and modernization of industrial production has its roots in the Fourth Industrial Revolution which has enabled the digitization and transformation of production based on modern automatic control methods, advanced IoT technologies and new platforms for the organization and management of production built on cyber-physical principles. Industry 5.0 - the forthcoming industrial revolution is purposefully building on the direction and results achieved and continues the set trends and aims to achieve further goals to optimize and improve conditions in people's professional and personal lives. Industry 5.0 can be defined as the next phase of industrialization in which people and advanced technologies work together in harmony to increase productivity, innovation and sustainability. Unlike its predecessor Industry 4.0 which focused on complex automation, Industry 5.0 puts more emphasis on humans, ensuring that technology serves people rather than replacing them. Such an understanding of new directions in complex digitization of processes requires the creation of new ways and forms of education in the near future, with an emphasis put on nurturing graduates with a higher level of skills and creativity. The new industrial revolution Industry 5.0 must therefore be based on new paradigms based on interdisciplinarity in education to ensure a high degree of long-term sustainability. This paper proposes novel forms and ways of research and education in line with the requirements and trends declared in the industry 5.0 concept.

Keywords:

Digitalization, Industry 4.0 and 5.0, research, education, artificial intelligence, IoT, edge computing.

Introduction

Industry 5.0 is an emerging concept that builds on the foundation of Industry 4.0 [5, 6, 7] but focuses on a more human-centric approach to industrial processes. While Industry 4.0 was centered around automation, IoT (Internet of Things) [2], Big data-analytics, AI, and robotics, Industry 5.0 aims to enhance collaboration between humans and machines, promoting the idea of personalized, sustainable, and efficient manufacturing systems. Industry 5.0 is focused on seven main core pillars [1, 3] (Fig.1). Main characteristic of the individual pillars:

1. *Human-Centric Production*: Industry 5.0 introduces a human-centric approach, emphasizing the integration of human creativity and intelligence with advanced technological capabilities. This new era aims to create a synergistic relationship between humans and machines, enhancing productivity while prioritizing human well-being and sustainability.

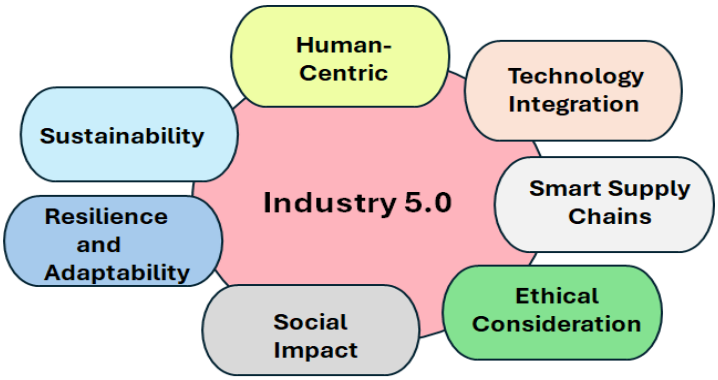

Fig.1. Core Pillars of Industry 5.0

2. *Sustainability:* Sustainability presents cornerstone of Industry 5.0. Focus on eco-friendly practices, energy efficiency, and reducing waste. Organizations adopt circular processes that minimize waste and environmental impact. Advanced Technologies based on AI and additive manufacturing enable optimization of resource usage, optimize and reduce energy consumption, with support of recycling initiatives.
3. *Resilience and Adaptability:* Building flexible and decentralized systems. Resilient industrial system is crucial for coping with disruptions and uncertainties. This involves developing flexible production capacities, robust supply chains, and adaptive business processes. Advanced digital technologies play a vital role in enhancing resilience by enabling real-time data collection, risk analysis, and automated mitigation measures.
4. *Technology Integration***:** Leveraging AI, IoT, IIoT, AR/VR, robotics, digital twins, and additive manufacturing. The transition to Industry 5.0 is powered by several advanced technologies:
   - Artificial Intelligence (AI): AI enhances decision-making, automates routine tasks and provides insights through data analysis.
   - Machine Learning: Machine learning control algorithms improve process optimization predictive maintenance, quality control process optimization.
   - Digital Twins: Digital twins create virtual replicas of physical assets, enabling real-time modelling, monitoring, simulation, and optimization.
   - Collaborative Robots (Cobots): Cobots work alongside humans, enhancing productivity and ensuring safety in complex tasks.
   - Extended reality (AR/VR): Key tools in Industry 5.0, allowing workers to visualize and interact with complex data and systems. In industrial manufacturing, AR can overlay critical information onto the physical workspace to help guide human operators, while VR can provide virtual training environments.
   - Blockchain technology: automates agreement processes among stakeholders, with smart contracts ensuring security, authentication, and all service - related automated actions in industry processes.
   - 6G network: is expected to align with the standard of intelligent information and communication with high energy efficiency, reliability, and traffic capacity.
   - IoT, IIoT within the context of Industry 5.0, offers opportunities to reduce operating costs by addressing communication network issues, optimizing waste management, enhancing the supply chain, and streamlining production processes.
   - Big data analytics: serves as another crucial enabling technology for handling vast amounts of data.

5. *Ethical Considerations***:** Fostering inclusive innovation, data security, and privacy. Ethical considerations for Industry 5.0 are essential in research, education and professional practice, ensuring that work is conducted with integrity, respect, and responsibility. Addressing ethical concerns involves identifying and mitigating potencial risks to participants, society, and the integrity of necessary research.
6. *Smart Supply Chains:* Optimized logistics with end-to-end visibility and autonomous systems. Industry 5.0 represents the next phase of industrial development, combining advanced digital technologies with human creativity and innovation to create more personalized, sustainable, and socially responsible manufacturing processes. Operations planning will need to be more responsive and adaptable to changing customer demands, while also emphasizing sustainability and social responsibility throughout the supply chain.
7. *Social Impact:* Improving worker well-being and enhancing the quality of life through technology. The fifth industrial revolution is innovative, resilient, socio-centric, and competitive while minimizing negative environmental and social impacts, respecting people, the planet, and prosperity.

1 Research and Education for Industry 5.0

Education for Industry 5.0 should be implemented in such a way as to take even greater account of people's skills and abilities, using and applying their talents, creativity, analytical critical thinking and acceptance of human qualities and needs for a pleasant life. One of the other important factors in education is the training of graduates who are part of and creators of new professions on the labor market that make a significant contribution to ergonomics, safety and comfort.

Industry 5.0 is pushing engineering education to evolve towards a more collaborative, interdisciplinary, and human-centered model, where technical expertise is complemented by the ability to work alongside AI, robots, and other advanced control intelligent technologies to solve real-world challenges. University engineering education for Industry 5.0 may be realized mainly in the study field of cybernetics, informatics and mechatronics requires an interdisciplinary approach that combines technical, humanistic, and ethical perspectives. As Industry 5.0 advances, universities will need to continually update curricula to address emerging technologies and ensure that students are equipped with the skills necessary to thrive in this evolving landscape.

Teaching professionals for Industry 5.0 operates on the core pillars (Fig.1) of Industry 5.0. The training of professionals for Industry 5.0 in the coming years [4] will be carried out mainly in technical universities and must focus more on the creation of such curricula and such teaching subjects that will further expand the use of digital and intelligent SW and HW technologies and systems in order to enhance and exploit such human creative and collaborative abilities and skills that have not been fully embraced in the Industry 4.0 challenge.

In the course of exploiting and fulfilling the Industry 4.0 challenge, the exploitation of the capability, creativity and collaborative intelligence of humans and machines has been somewhat forgotten in the past. Teaching for Industry 5.0 must already today be purposefully built and implemented in such teaching environment and such laboratories that will enable to acquire and strengthen the skills and creativity of students by validating intelligent control algorithms, communication, simulation, virtual reality on project tasks in teaching laboratories by training and testing on physical models of processes, robots and other intelligent devices, actuators enabling interaction and cooperation between humans and machines for complex control processes based on process data. It is expected that at technical universities, the study fields of automation, cybernetics, robotics, applied informatics and mechatronics will play a significant role in the education for Industry 5.0, both for undergraduate and graduate forms of study. For these study programs, it is possible to define the areas and future syllabus of subjects for Industry 5.0. Education for Industry 5.0 is based on enabling technologies (Fig.2) defining the fields and curriculums [4] of the subjects.

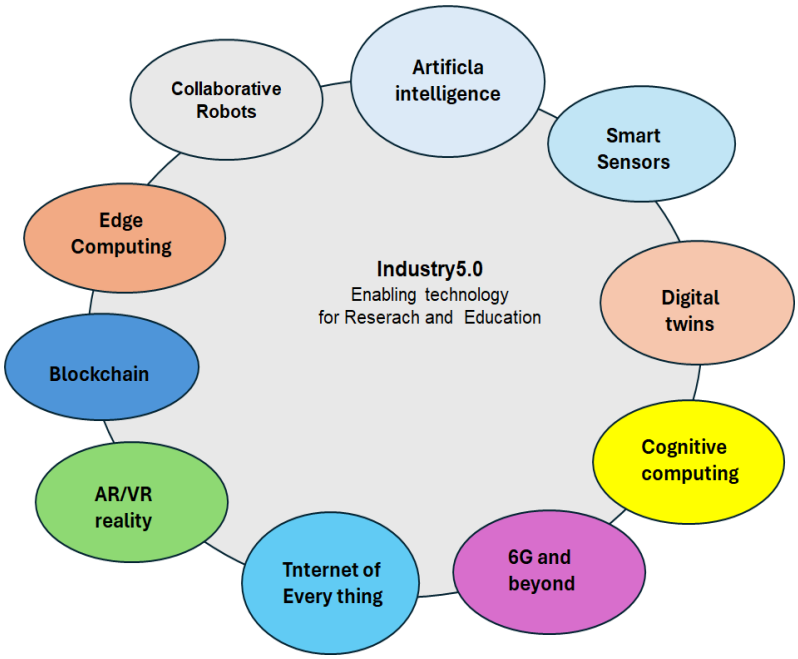

Fig.2. Enabling technology for the support of the research and education for industry 5.0

University education for Industry 5.0 focuses on the integration of advanced technologies, artificial intelligence (AI), automation, and human-machine collaboration to create smart, sustainable, and human-centric systems. Industry 5.0 emphasizes the collaboration between humans and machines to solve complex problems.

2 Proposal of Curricula for Graduate Education in Industry 5.0

Designing the main study programs for Industry 5.0 involves addressing the future of manufacturing, where human intelligence and creativity are integrated with advanced technologies like AI, automation, robotics, IoT, Big data analytics, Cloud computing, edge computing and cybersecurity. The primary goal is to create such educational programs that equip students with the skills needed to thrive in an increasingly automated, collaborative, intelligent and sustainable industrial environment.

Defining the main directions and the general curriculum of education and training for Industry 5.0:

2.1 Human-Centric Automation and Robotics

Objective: Equip students with knowledge and skills related to advanced robotics and automation, focusing on human-machine and human-robot collaboration.

Core Courses:

- Introduction to Automation and Robotics
- Human-Robot and Machines Interaction
- Control Systems
- Collaborative Robotics (Cobots)

- Edge Computing - real-time data processing, decentralized automatic control, reducing of latency in industrial environments
- Programming of control methods and algorithms for robots, technologies and complex industrial processes
- Ethical Implications of control methods and algorithm for industrial processes and robots

Skills Gained:

- Design of effective control methods and control structures
- Design and operation of collaborative human and robots
- Interaction between humans and autonomous systems
- Ensuring safe and efficient working environments

2.2 Artificial Intelligence and Machine Learning for Industry

Objective: Provide a foundation in AI and machine learning applications within industrial settings, emphasizing predictive maintenance, process optimization, and decision -making.

Core Courses:

- Machine Learning Fundamentals
- AI in Industrial Applications
- Predictive Analytics for Manufacturing
- Computer Vision for Manufacturing
- Extended reality for manufacturing - process visualization, optimization and control
- Data-Driven Decision Making

Skills Gained:

- Ability to develop AI models for manufacturing systems
- Implementing machine learning algorithms for predictive maintenance and process optimization
- Data-driven optimization of industrial processes

2.3 Cyber-Physical Systems and IoT

*Objective***:** Study the integration of physical processes with networked computing systems, enabling smart factories and interconnected devices.

Core Courses:

- Introduction to Cyber-Physical Systems (CPS)
- Internet of Things (IoT, IIoT) in Manufacturing
- Smart Factory Design and Implementation
- Edge Computing and IoT Security
- Industrial Networks and Communication Protocols

Skills Gained:

- Design and implementation of IoT systems for industrial processes environments
- Understanding and control the communication between physical devices and digital platforms
- Ensuring the cybersecurity of industrial IoT networks

2.4 Sustainability and Green Technologies in Industry

Objective: Focus on environmentally sustainable practices, energy efficiency, and circular economy principles in the manufacturing sector.

*Core Courses***:**

- Sustainable Manufacturing Practices
- Circular Economy and Resource Efficiency

- Energy Management in Industry
- Eco-friendly Materials and Processes
- Industrial Waste Management and Recycling

Skills Gained:

- Design and implementation of energy-efficient manufacturing systems
- Developing circular economy models within industries
- Promoting the sustainable material use and waste reduction

2.5 Digital Transformation for Industry 5.0

Objective: Provide a holistic view of the strategic integration of digital technologies in manufacturing, focusing on innovation and human-centered value creation.

Core Courses:

- Digital Transformation in Manufacturing
- Industry 5.0: The Human-Centric Approach
- Strategic Management of Digital Technologies
- Industry 5.0 Business Models
- Leading Change in the Digital Age

Skills Gained:

- Strategic decision-making for digital transformation in manufacturing
- Developing human-centered value propositions in the digital era
- Managing change and innovation in industrial environments

2.6 Advanced Manufacturing Technologies

Objective: Deep dive into cutting-edge manufacturing techniques such as additive manufacturing, advanced materials, and precision engineering.

Core Courses:

- Additive Manufacturing (3D Printing)
- Advanced Materials in Manufacturing Production
- Precision engineering, quality control and Nanotechnology
- Smart Manufacturing Processes Design
- Digital Twin, control and simulation in manufacturing

*Skills Gained***:**

- Expertise in 3D printing and other advanced manufacturing processes
- Use of modelling, simulation and digital twins for process optimization
- Knowledge of the latest materials for manufacturing innovation

2.7 Cybersecurity for Industry 5.0

Objective: Prepare students to safeguard the digital infrastructure of smart factories and other connected industrial environments from cyber threats.

Core Courses:

- Cybersecurity Fundamentals for Industry 5.0
- Securing of Industrial Control Systems Design
- Threat Detection and Response in Smart Manufacturing
- Blockchain for Industrial Cybersecurity
- Ethical Hacking and Vulnerability Testing

Skills Gained:
- Secure digital manufacturing environments
- Implementation of cybersecurity frameworks for IoT, IIoT and smart factories
- Managing industrial cybersecurity incidents and risks

2.8 Leadership and Collaboration in the Future of Work

Objective: Develop leadership skills necessary for managing a workforce that works alongside advanced technologies and is engaged in a human-centric approach.

Core Courses:
- Leadership in Industry 5.0
- Cross-Disciplinary Collaboration
- Control and managing human - machines and human-robot teams
- Organizational Change and Innovation in Process Control
- The Future of Work: Skills and Careers in Industry 5.0

Skills Gained:
- Leading teams that combine human expertise with advanced technologies
- Fostering collaboration across different disciplines
- Understanding the evolution of job roles and skills in the context of Industry 5.0

2.9 Capstone Student Project

Objective: Each study program should culminate in a capstone project where students work on real-world challenges related to Industry 5.0, such as designing a smart factory, implementing AI-driven solutions for sustainable manufacturing, or creating a human-robot and human machine collaborative environment.

2.10 Internship and Industry Collaboration

Objective: University partnering with industry leaders in automation, AI, automotive, energy, and chemical technological processes, biotechnologies, food industry and other manufacturing can give students real-time exposure to the applications and challenges of Industry 5.0. This could involve internships, project collaborations, and mentoring programs.

3 Education for Industry 5.0 - Curricula for Engineering Study in Cybernetics, Informatics, Mechatronics and Robotics

Main Areas of University Engineering Education for concept Industry 5.0, are mainly Cybernetics, Control engineering, Robotics, Informatics and Mechatronics. (Fig.3)

A Cybernetics (System and signal, models, control engineering, AI in modelling process control, edge computing process structure and methods):

University education for Industry 5.0 in the field of *Cybernetics* requires an interdisciplinary approach that combines technical, humanistic, and ethical perspectives. As Industry 5.0 advances, universities will need to continually update curricula to address emerging technologies and ensure that students are equipped with the skills necessary to thrive in this evolving landscape.

Main Areas of Education for Cybernetics in Industry 5.0:

A1 ***Systems Theory*** (will play a central role in Industry 5.0): Classification of systems, analyzing of the systems, mathematical models, dynamical systems, stability of the systems, digitalization of the systems, interactions between different system model, structure and parameters identification, adaptation, self tuning, optimization.

A2 ***Control system structures and methods, Cybernetics*** for Industry 5.0 involves mainly the study of control systems, control structure (feedback, feedforward, cascade, time delay, and their combination), classification of the control methods, basic signal processing for process control, communication between machines, robots and human. Understanding the fundamental principles of advanced control structures for different industry processes, control methods (conventional, advanced, robust and intelligent), edge computing platforms for industrial process control.

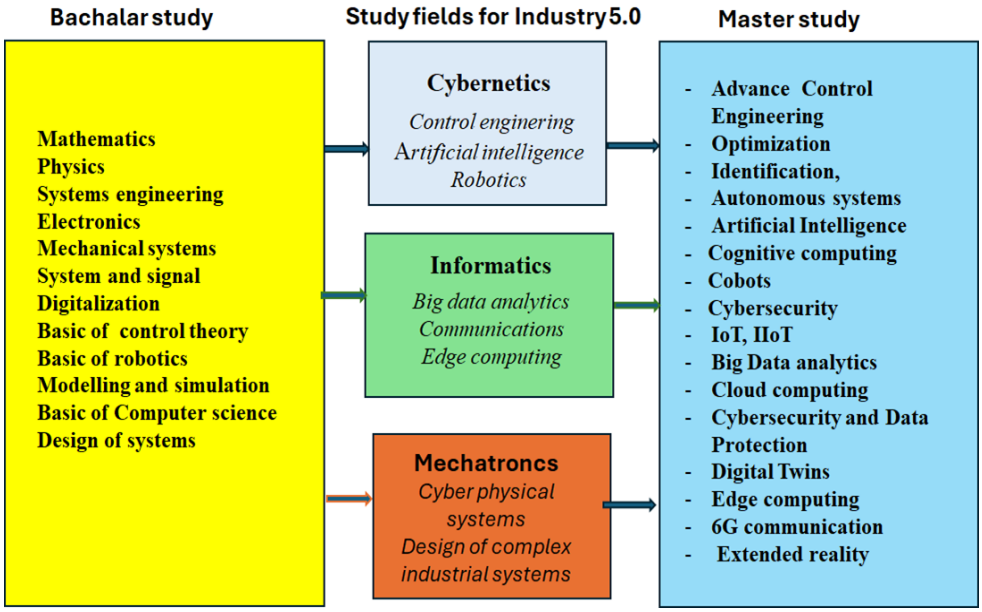

Fig.3. Main study field of education for Industry 5.0

A3 ***Artificial Intelligence (AI)*** education tailored for Industry 5.0 focuses on developing advanced, human-centric AI systems that collaborate with humans, machines and robots to enhance productivity, creativity, and sustainability. Industry 5.0 emphasizes the integration of human intelligence and AI, where machines support workers in more personalized, ethical, and collaborative ways. Artificial Intelligence (AI), among other technology enablers, is used to build services from a sustainable, human-centric and resilient perspective. *Human-centricity* is the core value behind the evolution of manufacturing towards Industry 5.0. AI/ML.

Integration: "human-centered artificial intelligence" refers to a model of AI development and implementation that prioritizes human needs, values, and perspectives. Essentially, it is an approach within the field of AI that focuses on engaging people with active inclusion of users, stakeholders, and industry experts throughout the entire AI development cycle, from design and development phases to practical implementation.

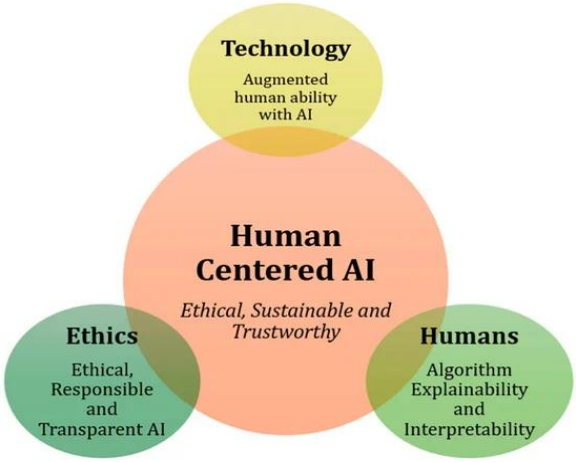

Fig.4. Human-centered AI (involves different aspects for Industry 5.0 [3]

Education in AI and machine learning is vital to enabling intelligent automation, decision-making, and autonomous systems. These technologies will support collaborative environments where human workers and machines interact seamlessly. For Industry 5.0 is significant:

Cognitive Computing: Cognitive manufacturing has emerged as the next evolutionary step within smart manufacturing for concept of Industry 5.0. Cognitive manufacturing caters to the industry's growing need for systems that are not just reactive but proactive, not just efficient but intelligent. In the context of Industry 5.0, the integration of cognitive computing and machine intelligence can significantly transform the industrial manufacturing processes. In the transition of Industry 4.0 to Industry 5.0, along with cognitive computing and machine intelligence, the integration of fog-cloud can further revolutionize future industries. Emphasizing how AI can be used to mimic human thought processes to enhance decision-making and problem-solving.

Generative Artificial intelligence (GAI): Application of GAI systems is one of the most exciting and successful advancements in concept of Industry 5.0. GAI aims to revolutionize how industries work, resulting in greater productivity, efficiency and innovation in many areas aspires to create highly optimized linked systems where devices, robots, and people may cooperate in perfect harmony.

A4 *Robotics AI and Autonomous Systems.* Industry 5.0 refers to the next phase of industrial development, focusing on collaboration between humans, machines and robots. This era emphasizes human-centric, sustainable, and resilient industrial production processes. Education in robotics for Industry 5.0 focuses on blending human creativity, AI, expertise, and advanced robotics (cobots) to enhance productivity, innovation, and quality of life.

Robotics in Industry 5.0: Focus on human-robot interaction, AI for robot learning, and ethical considerations in deploying robots in the workforce.

Collaborative Robots (Cobots): Cobots are a key element of Industry 5.0. These robots can work alongside humans, enhancing their capabilities and productivity. Unlike traditional robots that work independently, cobots work alongside human workers, sharing tasks and collaborating in real-time between intelligent machines and humans. Industry 5.0 introduces a more collaborative, sustainable, and personalized approach to manufacturing, with cobots at the heart of current industrial transformation.

B Informatics

Education Informatics for Industry 5.0 refers to the application of data science, AI, IoT, Big Data analytics, enable technologies, Cloud computing, and advanced edge computing to improve existing education systems, particularly in align Informatics field in the concept of Industry 5.0.

The main Areas of Education for Informatics in Industry 5.0:

B1 ***The Internet of Things (IoT, IIoT)*** industry is rapidly evolving, and one of the latest trends is the concept of "Industry 5.0."

B2 ***Cloud computing industry 5.0*** refers to the new generation of cloud technology, where advancements in AI, automation, and data analytics are seamlessly integrated into cloud services. In the context of Industry 5.0, cloud computing evolves beyond just providing infrastructure and platform services. Cloud computing integrate advanced technologies like:

B3 ***Automation and Robotics*****:** Cloud platforms will increasingly support automation tools that enable businesses to streamline operations and reduce human error. Cloud-based robotics, for example, will be an essential part of industries such as manufacturing and logistics.

B4 ***Artificial Intelligence (AI) and Machine Learning (ML):*** These technologies can help automate decision-making processes, optimize resource allocation, and deliver personalized services.

B5 ***Internet of Things (IoT):*** Cloud computing will be pivotal in processing and storing data from connected IoT devices, enabling real-time insights and actions.

B6 ***Edge Computing*****:** This is a step toward more decentralized computing, where data is processed closer to its source of the network, reducing latency and improving the speed of decision-making.

B7 ***Personalization and Customization:*** Cloud services will become more adaptable to individual and business needs, allowing for hyper-personalized experiences and optimized resources.

B8 ***Sustainability:*** The push toward more energy-efficient data centers and carbon-neutral computing resources.

C Mechatronics Education for Industry 5.0

Mechatronics is an interdisciplinary field that blends electrical engineering, mechanical engineering, control engineering informatics, robotics and AI, to design and create intelligent systems and products. Industry 5.0 is characterized by the integration of human creativity and collaboration with AI, robotics, and advanced automation systems. The main areas of mechatronics education they are relevant to Industry 5.0:

C1 ***Collaborative Robotics (Cobots).*** Mechatronics education for Industry 5.0 should include training on collaborative robotics that works alongside with humans in manufacturing environments.

C2 ***AI and Machine Learning Integration.*** The combination of AI with mechatronic systems is central to Industry 5.0. Mechatronics professionals should learn how to design systems that can teach, adapt, and optimize performance in complex process control.

Understanding control algorithms, machine learning models, edge computing, AR/VR and AI tools like neural networks and reinforcement learning is very important.

C3 ***Cyber-Physical Systems (CPS*****).** Education in this area will involve learning about sensors, actuators, embedded computer systems, and how to interface them with control software. CPS integrates physical processes with computers, robots, sensors using control and communication algorithms, for different (feedback and feedforward) control loop structures.

C4 ***Advanced Sensors and Actuators.*** In Industry 5.0, complex control systems often require more precise data collection and actuation to enhance control action, human-robot collaboration and decision-making. Learning about advanced sensors (e.g., vision systems, VR/AR systems, force, pressure and level sensors), actuators (e.g., smart materials, soft robotics) are essential for creating real time flexible, responsive systems.

C5 ***Additive Manufacturing with support.*** Industry 5.0 often leverages customized and on-demand production, which can be achieved using 3D printing technologies. In mechatronics education, students should gain experience with designing elements and subsystems that integrate 3D printers for manufacturing complex process parts and tools.

C6 ***Sustainability and Energy Efficiency.*** Proposal of curriculum for education in field Mechatronics in concept Industry 5.0:

- Introduction to Mechatronics (basic principles of mechanical systems, electrical systems, and programming)
- Control Systems (including modern techniques for adaptive, predictive, and intelligent control)
- Robotics and Automation (robot design, control systems, and collaborative robots)
- AI and Machine Learning for Engineers (focusing on their applications in mechatronics)
- Embedded Systems and IoT (integrating hardware and software for real-time applications)
- Sustainable Design and Manufacturing (Sustainable design and manufacturing especially in the context of Industry 5.0 focuses on integrating advanced technologies with environmental, economic, and social considerations).

Real Skills education in Mechatronics for Industry 5.0:

- Programming Languages: Python, C/C++, MATLAB, LabVIEW, ROS (Robot Operating System)
- Tools/Platforms: SolidWorks, AutoCAD, Simulink, TensorFlow, Unity (for extended virtual simulations)
- Hands-on Experience: Work with robotic kits, IoT devices, and real-time operating system applications (such as automation platforms)

4 Examples of Teaching for the Concept of Industry 5.0 at Selected Leading European Universities

1. ETH Zurich (*Eidgenössische Technische Hochschule*, Switzerland) - has a strong focus on automation, robotics, artificial intelligence, and sustainable development, all key aspects of Industry 5.0. They offer programs in automation, robotics and autonomous systems, integrating the concept of human-centric AI into their research and teaching.

2. Technical University of Munich (Germany) - offers interdisciplinary programs that cover the convergence of technology and society, which can align with the principles of Industry 5.0. They focus on AI, automation, robotics, and sustainable innovation, which are at the heart of Industry 5.0.

3. Politecnico di Milano (Italy) - known for its engineering and design programs, Politecnico di Milano is involved in researching digital transformation, Industry 4.0, and Industry 5.0, with projects focused on human-machine collaboration, IoT, and industry automation.

4. The University of Manchester (UK) - through its Advanced Robotics Research Centre, the University of Manchester is involved in research and education related to robotics and human-centric AI, which are central to the Industry 5.0 framework.

5. European Union Research Initiatives: the EU is heavily investing in Industry 5.0 through initiatives like the Horizon Europe program, which funds research and innovation projects across various sectors, including AI, robotics, and sustainable manufacturing.

6. Industry 5.0 and Human-Centric AI Masters and PhD programs - various universities across Europe have started to offer specialized master's and PhD programs focused on the human-centric approach to AI, robotics, and automation, preparing students for the demands of Industry 5.0.

Conclusion

Industry 5.0 redefines the role of humans in the manufacturing process. It leverages advanced technologies to create a more collaborative and innovative production environment, ultimately leading to better products, improved efficiency, and a more engaged workforce.

Industry 5.0 represents a new era where human creativity [2] and advanced technologies come together to create more efficient, innovative, and sustainable manufacturing processes. By focusing on the collaboration between humans and machines, Industry 5.0 enhances productivity, fosters innovation, and improves working conditions across various sectors.

In education [4], Industry 5.0 refers to the cooperation between these advanced technologies, educators and students to enhance the efficiency and effectiveness of teaching and learning. Industry 5.0 technologies have the potential to revolutionize the way students learn, and teachers teach.

The benefits are numerous, including higher efficiency, greater customization, better working environments, and increased sustainability. However, it is essential to address the challenges associated with this transition, such as workforce training, data security, integration costs, and ethical concerns.

Industry 5.0 is a term used to describe the integration of human creativity and craftsmanship with the speed, precision, and consistency of advanced machines and AI systems. Unlike Industry 4.0, which aimed at automating processes and reducing human intervention [5], Industry 5.0 focuses on enhancing human capabilities through technology. It emphasizes a collaborative relationship between humans, machines and robots.

University education for Industry 5.0 requires an interdisciplinary approach that combines technical, humanistic, and ethical perspectives. As Industry 5.0 advances, universities will need to continually update curricula to address emerging technologies and ensure that students are equipped with the skills necessary to thrive in this evolving landscape.

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