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Contents

Editorial

Dear readers,

The current stage in research and teaching is focused on the development of advanced intelligent methods and technologies in a wide range of both industry and health and service sectors. The papers in this issue therefore have a broad scope with the aim of illuminating some new perspectives on the effective use and implementation of advanced intelligent methods and algorithms in real life. Articles in this issue are under one common contemporary trend of Industry 5.0 mentioning visualization, virtual reality, artificial intelligence and advanced communication networks.

Thank you for your contributions, we welcome your latest research results and solutions and we look forward to further collaborations.

Ing. Juraj Štefanovič, PhD.
ITA Executive editor

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RESEARCH AND EDUCATION FOR INDUSTRY 5.0

Štefan Kozák, Eugen Ružický, Ján Lacko, Juraj Štefanovič

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.

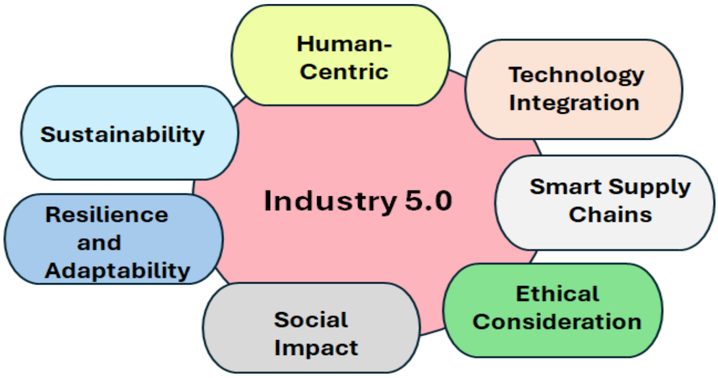

Fig.1. Core Pillars of Industry 5.0

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.

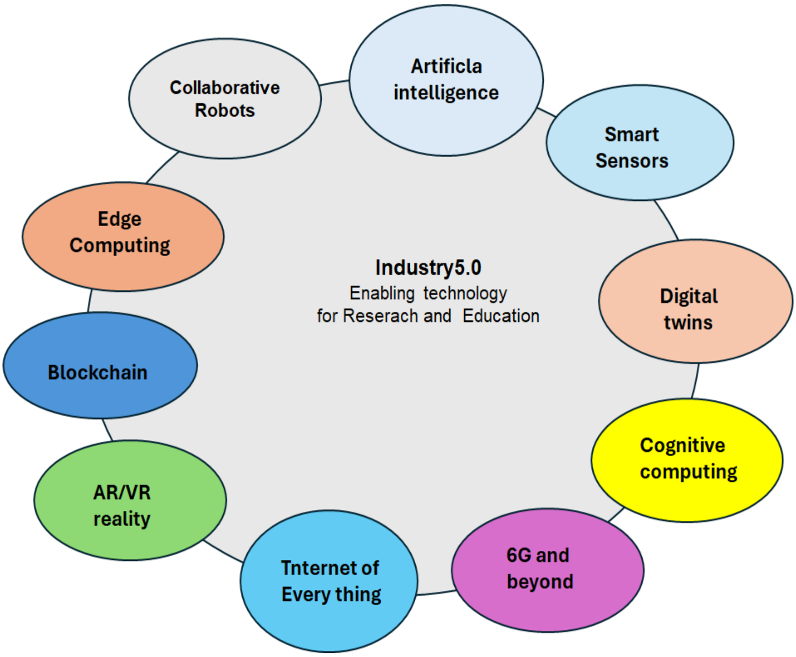

Fig.2. Enabling technology for the support of the research and education for industry 5.0

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.

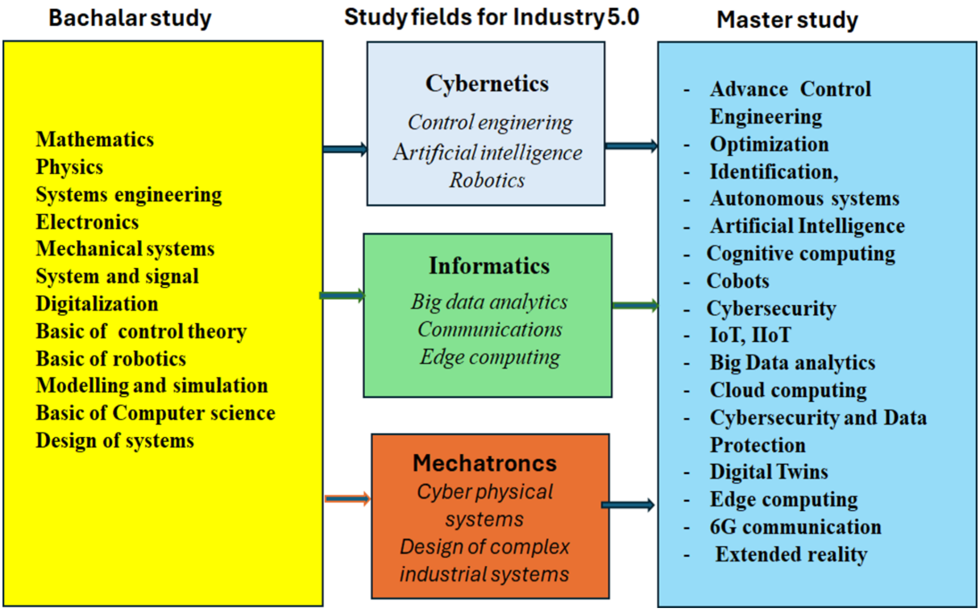

Fig.3. Main study field of education for Industry 5.0

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.

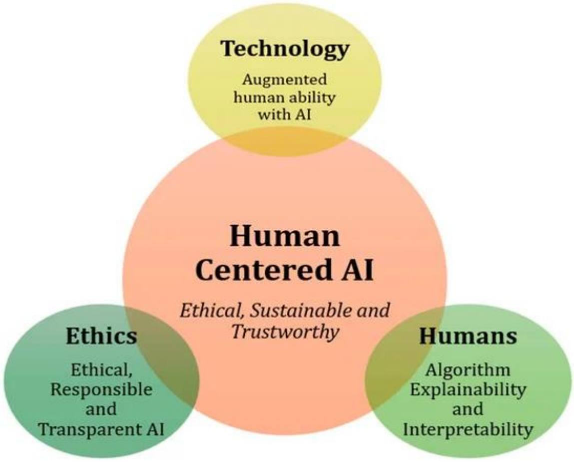

Fig.4. Human-centered AI (involves different aspects for Industry 5.0 [3]

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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References

[1] European Commission, Industry 5.0: Towards more sustainable, resilient and human-centric industry (January 2021). https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/industry-50-towards-more-sustainable-resilient-and-human-centric-industry-2021-01-07_en, Accessed 20 Oct 2022.

[2] Ashima R. et al.,: Automation and manufacturing of smart materials in additive manufacturing technologies using Internet of Things towards the adoption of Industry 4.0, J. Materials Today: Proceedings, Vol. 45(6), 2021, Page 5081-5088, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2021.01.583.

[3] Breque M. et al.: Industry 5.0 Towards a sustainable, human-centric and resilient European industry, In Industry 5.0 Towards a sustainable, human-centric and resilient European industry, 2021, Luxembourg: Publications Office of the European Union.

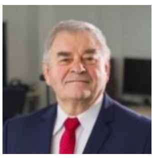
[4] A. D. Lantada: Engineering education 5.0: Continuously evolving engineering education, International Journal of Engineering Education, Volume 36, No.6, pp.1814-1832. 2020

[5] S. Kozák, E. Ružický, J. Štefanovič, F. Schindler: Research and education for industry 4.0: Present development, IEEE Conference, Cybernetics and Informatics, 2018/1/31

[6] M. Huba, Š. Kozák : From e-Learning to Industry 4.0, International Conference on Emerging eLearning Technologies and Applications (ICETA), November 2016, DOI:10.1109/ICETA.2016.7802083G.

[7] Z. Képešiová, Š. Kozák : Smart Factory in Industry 4.0 Journal Information Technology Applications, Vol. 10 No. 2 (2021)R

Authors



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VISUALIZATION OF PRODUCTION DATA USING NODE-RED

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Abstract:

The paper effectively addresses the critical integration of SCADA systems in modern industrial automation, specifically focusing on the visualization and control of production processes. By examining a real-world application — using a school model production line controlled by a PLC device and visualized through the Node-RED platform — the paper offers valuable insights into the practical implementation of such systems. The proposed work not only highlights the importance of data visualization in streamlining operations, but also underscores the growing need for efficient control and monitoring of production processes. Through both theoretical analysis and hands-on implementation, the thesis demonstrates how combining SCADA technologies with user-friendly environments can significantly improve operational oversight, ensuring smoother automation workflows and long-term data management.

Keywords:

SCADA, PLC, visualization, production process, control algorithm, Node-Red, simulation.

Introduction

The development, implementation, and design of SCADA (Supervisory Control And Data Acquisition) systems have gained increasing importance in recent years, driven by the rapid advancements in information and communication technologies.

The primary role of SCADA systems is to control technological processes, representing industrial automation. These systems not only manage and monitor processes but also handle and archive vast amounts of data over extended periods. Process control, based on the evaluation and analysis of results, leads to improvements in technological processes within a company, such as enhanced product quality, increased reliability, higher efficiency, and reduced energy consumption.

In this work, we focus specifically on the design and implementation of a SCADA system for a real laboratory model of a production line, controlled by a PLC (Programmable Logic Controller) device and visualized within the Node-RED environment. This study aims to explore the integration of SCADA systems with educational models, offering insights into how industrial automation principles can be applied in smaller-scale settings.

Through this practical application, we demonstrate the potential for SCADA systems to optimize production processes, improve data management, and foster more efficient operations in both industrial and educational contexts.

1 Production

Production processes refer to all activities involved in a series of steps or actions dedicated to transforming raw materials or components into finished products. These processes often utilize machinery, tools, equipment, and other resources to perform tasks such as production, assembly, packaging, and transportation. At the core, manufacturing processes involve the interaction of manufacturing forces, aimed at creating a specific product. Every manufacturing process requires human involvement and labor resources.

Production can be characterized as a method in which economic resources—such as labor, capital goods, and land—are utilized to provide goods and services to consumers. The primary objective of manufacturing is to ensure the efficient and productive production of goods for sale, aiming for quick delivery to customers without compromising product quality.

There are numerous types of production processes that companies can use, depending on their production goals, manufacturing volumes, and technological tools or software systems in place. These processes can vary significantly depending on the type of product being produced, the industry, and the specific manufacturing techniques applied.

This paper aims to explore the diversity of production processes and their adaptation to different sectors, as well as the technological advancements that shape them. By examining the interconnected nature of production methods, it provides insights into optimizing manufacturing efficiency while maintaining high-quality standards [1].

Efficient production processes are essential for companies to maintain their competitiveness and meet customer demand while upholding high quality standards and controlling costs. In recent years, automation of production processes has become increasingly popular due to its ability to enhance efficiency and consistency, while simultaneously reducing labor costs.

a) Automation of production processes

Automation allows companies to streamline production workflows, minimize human error, and improve product quality by ensuring precise and repeatable operations. The integration of automated systems and robotics into production lines has revolutionized industries, enabling faster production times, lower operational costs, and higher output volumes. This trend is not only beneficial for large-scale manufacturers but is also becoming more accessible to small and medium-sized enterprises (SMEs), who can leverage automation technologies to remain competitive in an evolving marketplace.

Automation refers to the implementation of technology that reduces the need for manual labor and enables systems to make automated decisions based on computer algorithms. It involves the application of machines to tasks that were previously carried out by humans or, increasingly, to tasks that would otherwise be impossible to perform [2].

The key advantage for businesses is the reduction of operational costs, as automation streamlines workflows and reduces the reliance on human labor for repetitive or complex tasks. Automation also enhances workplace safety by performing hazardous or physically demanding tasks that may pose risks to employees.

The impact of automation has been transformative in industries where it has been adopted. It has revolutionized manufacturing, logistics, and various other sectors, and it is rare to find an aspect of modern life that has not been affected by its advancements. The widespread use of automation has not only increased productivity but also contributed to more consistent product quality and quicker response times to customer demands [3].

Automation can also be defined as a technology related to the execution of a process using programmed instructions combined with automated feedback control to ensure that they are executed correctly. The resulting system is able to operate without human intervention.

The very development of this technology has become increasingly dependent on the use of computers and computer-related technologies. As a result, automated systems are increasingly sophisticated and complex. Today's advanced systems represent a level of capability of control and performance that in many ways exceed the ability of humans to perform the same activities. Thus, if a controlled system behaves in a way that meets our needs, it means that control is not necessary in this case. Control is associated with certain behaviours of the system, that is directed towards some goal. For example, the field of PLC automation is the field of system control with goal-directed behaviour (from the steam engine to modern digital control systems) [2, 4].

b) Programmable logic controller (PLC)

PLC is a programmable computing device used to control electromechanical processes, especially in the industrial sector. It is a user-programmable digital automatic machine which has some specific features compared with conventional computers. The role of PLC is to control the functions of the system using internal programmed logic. Companies around the world use PLCs to automate their most important processes [6].

PLCs are widely used in various industries due to their speed, ease of use and programmability. PLCs can be programmed in a variety of ways, from ladder logic based on electromechanical relays to special modified programming languages such as BASIC and C. Today, most PLC devices use one of the following five programming languages: Ladder Diagram (LD), Structured Text, Function Block Diagram, Instruction List, Flowchart [5].

Today, PLC systems are used in a variety of industrial applications, including manufacturing, energy, transportation and many other areas. Their functions are constantly expanding and improving to handle increasingly complex processes. Examples of PLC device applications in mechatronics include controlling motor speeds, monitoring the position and attitude of equipment, controlling pneumatic and hydraulic systems, controlling measurement and sensor equipment, and more. In general, it can be said that PLC systems are very important for the efficient control and automation of industrial processes in the field of mechatronics and for improving the overall performance and efficiency of machinery and equipment [6].

Over time, PLCs have evolved and adapted to the specific needs of the industrial environment. Due to their flexibility, PLCs can be used in a wide range of industries. PLC devices can be individually wired to control and regulate the performance of manufacturing machines that can meet the high demands of modern industry. PLC can usually be installed directly on the production machine, which implicitly saves the necessary space capacity. In addition to the ability to remotely control the PLC, one of its greatest advantages is the ability to communicate with other peripherals. However, depending on the area of application, it is essential that the PLC operator must have expert knowledge [7].

The components of a PLC device are divided into three main categories: inputs, outputs and CPU (Central Processing Unit). PLCs collect data from production by monitoring the inputs to which machines and devices are connected. The input data is then processed by the CPU, which applies logic to the data based on the state of the input. The CPU then executes the logic of the user-created program and sends data or commands to the machines and devices to which it is connected.

Inputs can include on/off states for elements such as mechanical switches, buttons and encoders. High/low states for elements such as temperature gauges, pressure sensors, liquid level detectors, or open/closed states for elements such as pumps. The second type of input, human-assisted inputs, includes pushbuttons, switches, sensors from devices such as keyboards, touch screens, remote controls or card readers. Outputs can be characterised as physical actions or visual results based on PLC logic in response to the corresponding inputs. To give an idea of the physical outputs and also for an idea of what they contain, it is for example starting a motor, turning on lights, a valve tripping or a pump shutting down. Visual outputs are sent to devices, such as printers, projectors and monitors [5].

The functionality of PLC devices is based on cycles. First, the PLC recognizes the state of all connected input devices. The PLC device runs a user-created program that uses the state of the inputs to determine the state to which the outputs should be switched. The PLC then adjusts the output signals for each corresponding device. Once all of these steps, the PLC performs a cleanup (maintenance step) that includes an internal safety diagnostic to ensure normal operating status. The PLC device restarts the cycle after completion of each process. After the restart, the inputs are checked again. Thanks to the wide range of available communication devices, it is possible to connect the control device to almost any PLC [5, 6].

c) Visualization systems

System visualization is the process of mapping the flow and function of a system, server or data flow. Visualizations help to diagnose problems faster, communicate between departments and efficiently build or update the system. The concept of a visualization system is the consistency of all parts of the system, where information retrieval affects, for example, perception (brightness, colour contrast, character size), coding (icons, codes) and organization (structure) [8].

Visualization is a field that deals with the processing and presentation of data. In the broader sense, it compares all data from different sources. It represents a technique for creating images, diagrams or animations to communicate a message. At present, visualisation has increasingly expanding applications in science, engineering, medicine and so on. A typical visualisation application is the field of computer graphics. The invention of computer graphics may be the most important development in visualisation since the invention of central perspective in the Renaissance. The development of animation also has helped to advance visualization [9].

The field of computer graphics is a large and diverse area, which is the intersection of computer science and design. It deals with the whole process of creating computer generated images, from the creation of 3D digital models through the texturing process, rendering and lighting these models, to the digital display of these representations on screen. This process presents simple techniques for rendering objects on converting mathematical representations of three-dimensional objects into a two-dimensional image on screen. Computer graphics can thus be understood broadly and generally as any graphical representation created by a computer.

Information visualization is the practice of presenting data in a meaningful and visual way that users can easily interpret and understand. This includes data visualizations and dashboards. Information visualization is an effective way to share knowledge in a format that is digestible for non-experts. It typically shows relevant context in the data, allowing decision makers to more easily draw conclusions and take informed action. Information visualisations are often created with the audience in mind and are designed to present important information that needs to be understood. By having an idea of how the visualizations will be used, the visual designer can determine the best format for arranging the information and visuals to be used [6].

Contemporary information visualization is becoming increasingly popular as advanced tools and technologies enable interactive features that allow users to manipulate data in real time. This allows non-technical users to explore topics from different perspectives and easily gain insight into the data.

There are many software tools available for process visualization, which help in mapping, analyzing, and optimizing various manufacturing and business processes. These tools play a crucial role in improving efficiency, communication, and decision-making within organizations. There are some of the most well-known and widely used software tools for process visualization. Each of these tools is valuable for process visualization and automation, and their use depends on the specific needs of the industry or application. WinCC and AVEVA InTouch are more tailored for traditional SCADA applications in industrial environments [11,12], while Promotic offers greater flexibility and customization [10].

Node-Red (Fig.1) is a graphical development tool (application) that is gradually becoming the industry standard for the development of industrial IoT applications that collect, process, and share data over the Internet. It is used to connect events and data from, for example, physical devices (sensor), social networks and services such as email, SMS or notifications. It also serves as a programming tool to connect hardware devices (e.g. interfacing with PLCs and Arduino), APIs and online services in new and interesting ways [13].

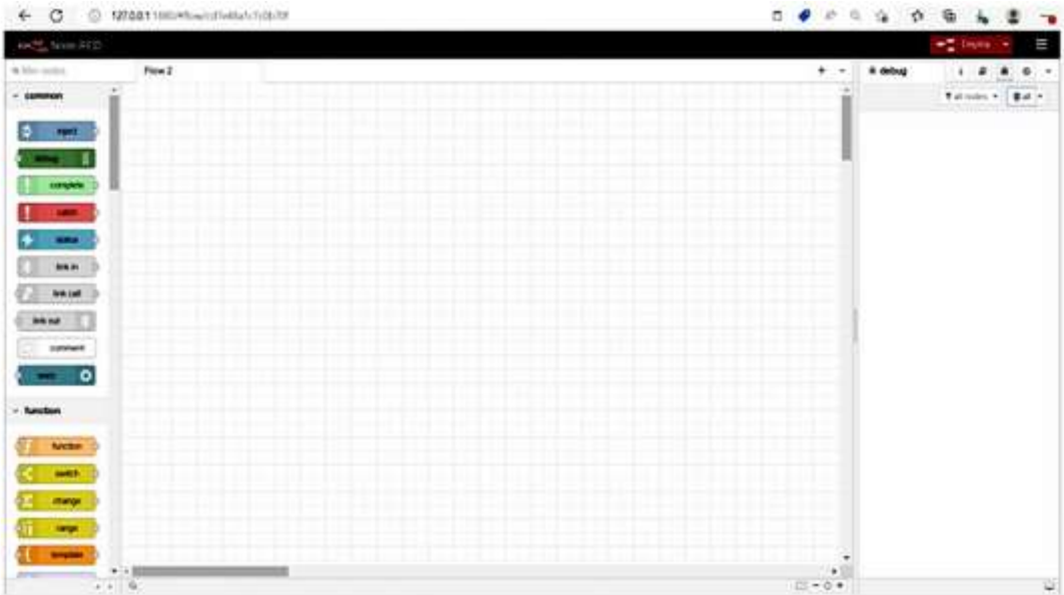

Fig.1. Node-Red environment.

Node-Red is an open-source tool originally developed by IBM's Emerging Technology Services team, now part of the OpenJS Foundation. It is supported by Windows, Linux and Mac OS platforms. It is also possible to use the nodes application, but this requires knowledge of the JavaScript programming language [14].

Flow-based programming was invented by J. Paul Morrison in the 1970s. It is a way to describe the behavior of an application as a network of nodes. Each node has a clearly defined purpose - it receives, transmits or manipulates data. The network is responsible for the flow of data between nodes. Due to its simple logic, this model allows a wider range of users to understand the whole process.

Thus, it is possible to get an idea of its operation from the model without having to understand the individual lines of code of each node. A flow is created by combining any number of nodes. They are connected by wires formed by dragging the grey output of one node to the grey input of another node [14].

Node-Red consists of a web-based runtime environment based on Node.js. In the browser, it is possible to create an application by dragging nodes from the palette onto the canvas and start connecting them. Node-Red provides the aforementioned web-based flow editor, which makes it easy to link flows using a wide variety of nodes in the palette. Flows can then be deployed to runtime with a single click, at which point the application is deployed to the runtime environment in which it subsequently runs [14,15].

There is a wide range of libraries available, and a short selection of the default libraries available in the main panel of the Node-Red tool can be seen in (Fig.1).

The Node-red-dashboard is a collection of nodes that can be used to create a web dashboard that interacts directly with a given flow [16].

Node-red-contrib-s7 is a collection of Node-Red nodes serving as an interface to the Siemens S7-PLC. Each single link to a PLC device represents an S7 endpoint configuration node. It is possible to configure the PLC address, also the available variables and their addresses, and the cycle time for reading the variables.

2 Case Study

The primary piece of equipment used at this researsch was Fishertechnik model of a production line with two machining stations from. This is an ideal training, simulation and demonstration model for industrial automation training and demonstration. The production line model is mounted on a solid wooden board. Voltage is optionally available in standard 9V as well as the world industry standard 24V. 24V voltage is required for unconditional operation with PLC equipment.

The production line model (Fig.2) contains 2 machines (milling and drilling station) and 4 conveyor belts arranged in a U-shape. The conveyor line uses 8 type XS DC motors, 2 sliders, 4 pushbuttons serving as limit switches, 5 phototransistors and 5 LED light barriers. The model has a circuit board with relays for reversing the direction of rotation of the motors. All inputs and outputs can be connected to a jack plug (26-pin, 2.54 mm pitch) or to series terminals with push-in terminals [17].

Fig.2. Laboratory model of production line [17].

SIMATIC S7-1200 (Fig.3) is a modular, compact, versatile and comprehensive control system for automation applications. A flexible design, a communication interface that meets the highest communication standards in the industry, and a wide range of built-in functions make this PLC an entry-level model that is part of automation tasks.

The digital inputs on the PLC device operate at 24V, with a voltage level in the 0-5V range considered a logic zero and a level in the 15-24V range considered a logic one. The analog inputs have a range of 0 to 10V. The digital outputs have a voltage level of 24V [19].

Memory The PLC 1200 has up to 50 KB of integrated main memory with a seamless interface between program and data memory on the SIMATIC S7-1200. The flexible boundary between data and program ensures efficient use of all disk space.

In addition to the main memory, the SIMATIC S7-1200 includes 2 MB of integrated memory and 2 KB of backup memory in case of a power failure. For transferring the necessary project to multiple base units and updating the firmware, the SIMATIC memory card is available in two sizes: 2 MB or 24 MB.

Fig.3. SIMATIC S7-1200 [18].

The control algorithm was created in TIA Portal environment using the Ladder diagram language. In the tables, IO tags were created with the relevant type and address according to the individual sensors (inputs) and actuators (outputs) connected to the PLC.

The implementation of the algorithm consisted of controlling the conveyors and sliders on the production line so that the product was transferred through the entire line. When the product is detected at the first light sensor, conveyor 1 is started and stopped at the second sensor. The slider 1 will move backwards until the limit switch is pressed, causing conveyor 1 to restart for 2 seconds. The motion of the slider and conveyor 2 is then activated, which moves the product to light sensor 3. This sensor activates machine tool 1 for 5 seconds.

In the next phase, the product is moved to conveyor 3, where it is detected by sensor 4, activating machine tool 2 for 7 seconds. After the product has been processed, it is moved from conveyor 3 by slider 2 to conveyor 4, where it is dropped off the line. The program also includes the treatment of product loss using timers and alarms.

The program is divided into function blocks in TIA Portal, such as Alarms, Counters and Conveyors. In addition, the motor hours of the actuators and the number of times the motors are switched on are measured. An algorithm for counting and resetting the number of finished products at the exit of the line has been developed based on the detection by the last light sensor #5, as well as an algorithm for counting the number of products on the line. The laboratory model can be controlled in both automatic and manual mode.

The Node-Red environment was used to implement and design the visualization environment used to control the production line model. The Node-Red program is written in JavaScript running on the NodeJS platform. The communication between the PLC devices and the personal laptop was realized through an Ethernet cable. A library called node-red-contrib-s7 was needed to communicate between the Node-Red and TIA Portal (PLC device).

For the visualization, it was necessary to download the libraries that offered us the relevant parts to control the correct operation of the production line, for example the most used library for communication and for visualization node-red-dashboard. It was necessary to implement individual functions, e.g. buttons, warps and switches, to control the functionality of the production line. We used the JavaScript programming language to implement the backlighting of the buttons in manual mode and for "moto-hours" (listing seconds, minutes, hours), number of products on the line and number of finished products.

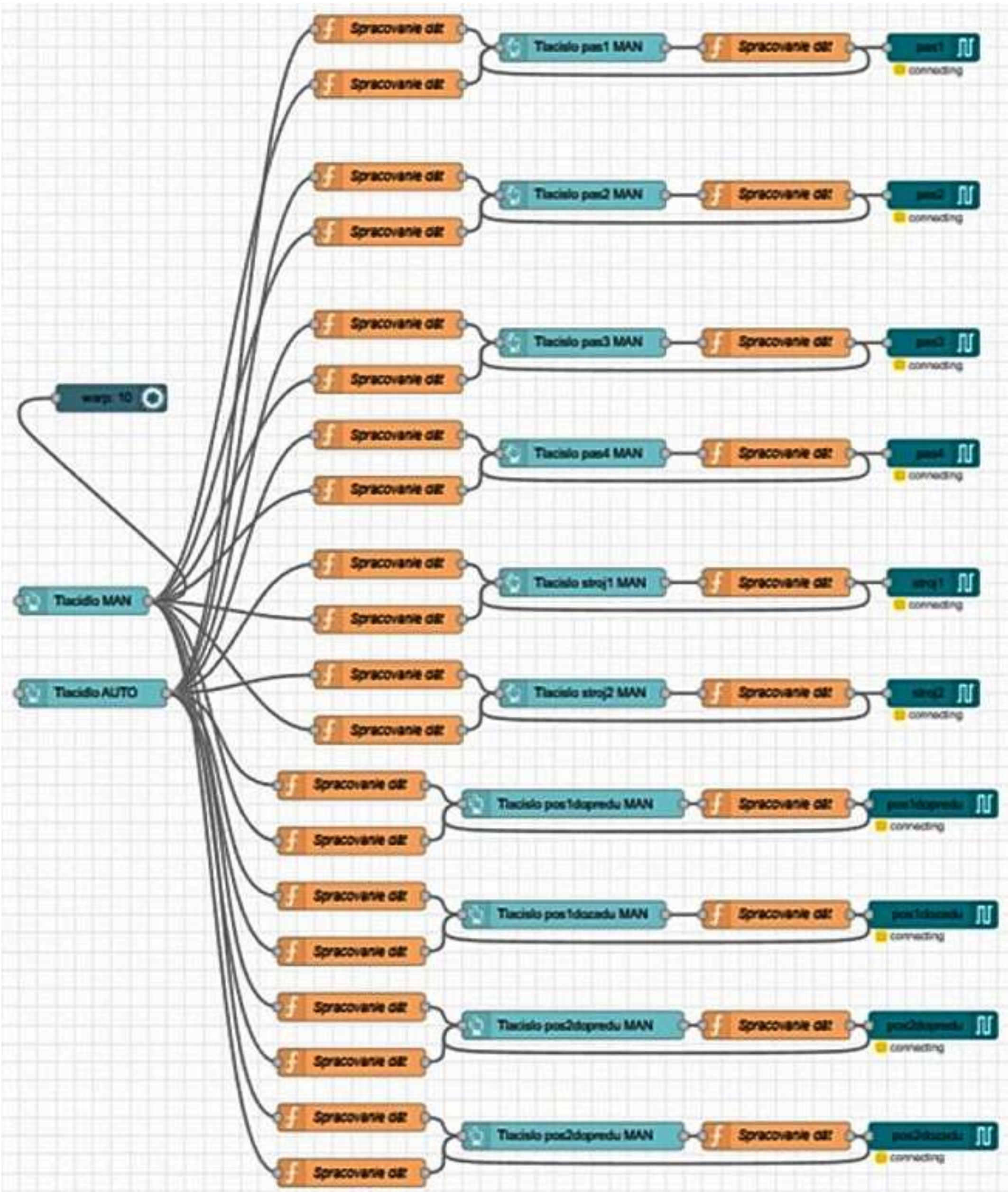

Fig.4. Automatic and manual control in Node-Red environment.

The production line starts when the start button is pressed (Fig.5), at that moment the automatic mode is running. To switch from the automatic mode to manual mode, there is the button called MAN, where the backlight of the buttons is set to green and red. If all the buttons used for manual mode are illuminated in red, this indicates that the entire production line operation is stationary and waiting for the operating personnel who decide to operate the line component manually with a button. The illumination of the button to green will not occur until it is pressed by the operating personnel. The AUTO button is used to switch back to automatic mode from manual mode.

Fig.5. HMI in Node-Red environment during manual mode (MAN, AUTO buttons on left side). Four columns: Control, Sliders, Machines+Conveyors, Moto-hours.

It was necessary to implement a graphical representation of "moto-hours" in the visualization, in seconds, minutes and hours (Fig.6). The visualization will show how long the product was on the conveyor belt and how long it was under the machine tools for that section. A count is also taken of how many products are on the line and how many products have been produced.

We have set a reset option for each associated function to list the "moto-hours" of the individual components. If the operating personnel chooses to reset the running time counting of a given product via a component, they have the option to use the reset button and the given values of seconds, minutes and hours will be counted from the beginning (from 0). The option to reset the count of products present on the line and the number of products produced is available by pressing the reset button.

Conclusion

The aim of the paper was to learn about the design and implementation of a SCADA system for a real school model of a production line, which is controlled by a PLC device and visualized in the Node-Red environment. We provided new insights and details about the PLC device as well as the Node-Red visualization environment.

After analyzing and familiarizing ourselves with the current state of the art, we focused on their implementation. The first step was the implementation of the production line control algorithm on the PLC device, which we implemented in the TIA Portal environment. Subsequently, we described the correct functionality of the production line algorithm. After this step, we focused on communication between the PLC device and the visualization system, which was implemented and designed in the Node-Red environment.

We made a visualization model through which it was possible to control the operation of the production line, where we described the implementation of the control of the visualization model. From the achieved results, was achieved the functionality of the SCADA system algorithm for the real school model of the production line, as well as the possibility of controlling the visualization model of the production line through the Node-Red application.

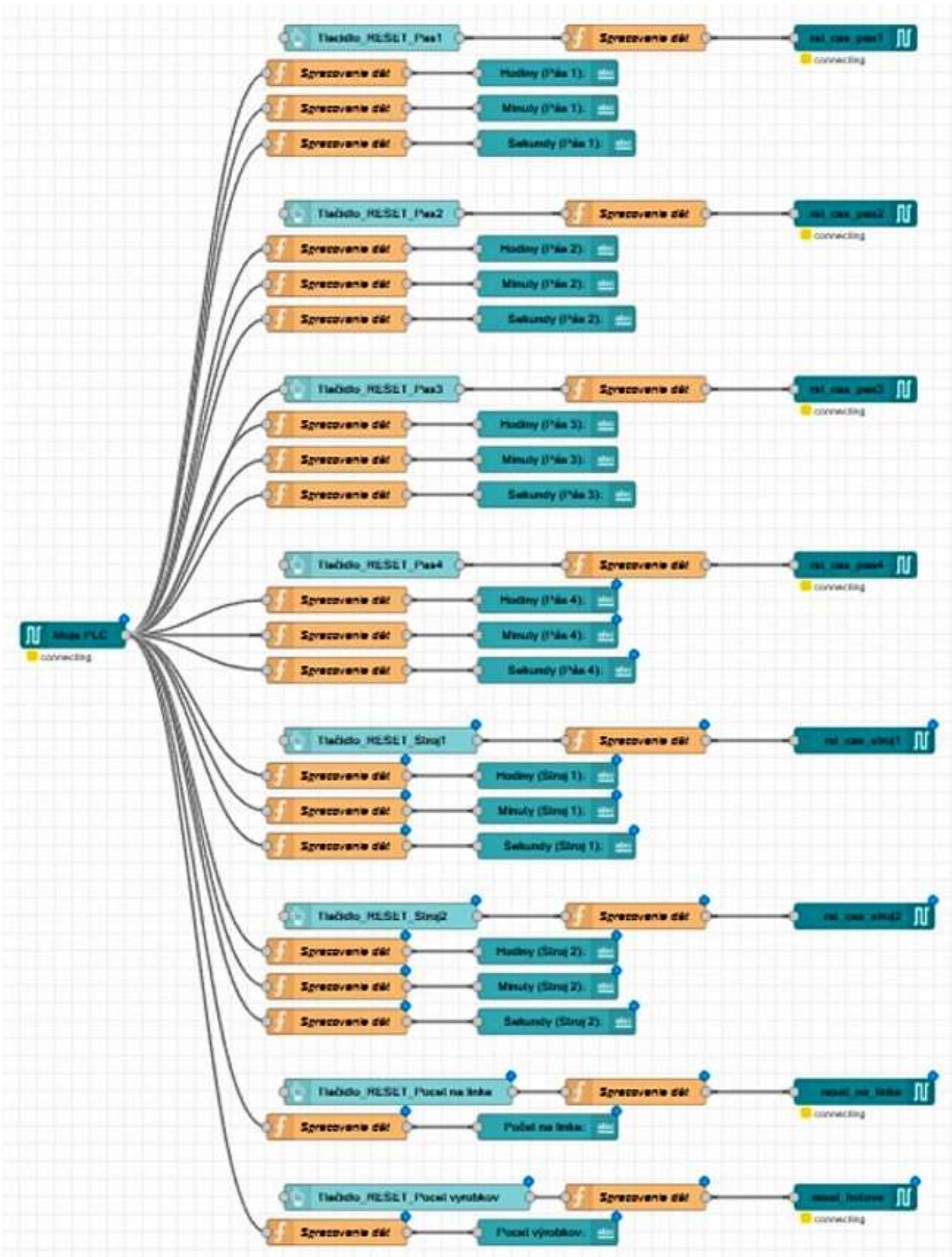

Fig.6. Moto-hours in Node-Red environment.

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References

[1] Indeed Editorial Team: Production Process: Definition and Types for Businesses To Use [Online]. September 30, 2024.
Available: https://www.indeed.com/career-advice/career-development/production-process

[2] T. Pettinger: Automation meaning and examples [Online].
Available: https://www.economicshelp.org/blog/glossary/automation-meaning-and-examples/

[3] M. P. Groover: automation [Online]. December 15, 2024.
Available: https://www.britannica.com/technology/automation

[4] P. Kuna: Fundamentals of automation (In Slovak). Nitra: UKF, 2015. 57 p.
ISBN 978-80-558-0841-3

[5] Inductive automation: PLC: Programmable Logic Controller. PLC Basics, Operation, Programming and the Future of PLCs [Online]. February 24, 2020.
Available: https://inductiveautomation.com/resources/article/what-is-a-PLC

[6] J. Cigánek, F. Žemla: PLC systems in mechatronics (In Slovak).
Bratislava: Chemical library STU, 2023. 88 p. ISBN 978-80-8208-097-4

[7] Paessler: IT Explained: PLC [Online]. Available: https://www.paessler.com/it-explained/plc

[8] Lucidchart: Why visualizing systems is essential in the Next Normal [Online]. Available: https://www.lucidchart.com/blog/why-visualizing-systems-is-essential-in-the-next-normal

[9] Spotfire: What is information visualization? [Online].
Available: https://www.spotfire.com/glossary/what-is-information-visualization

[10] Microsys: PROMOTIC SCADA visualization software [Online].
Available: https://www.promotic.eu/en/index.htm

[11] Siemens: SIMATIC WinCC - Process visualization with Plant Intelligence [Online], 2010.
Available: https://www.pcne.eu/uploads/tx_etim/siemens_wincc.pdf

[12] AVEVA: AVEVA InTouch HMI [Online].
Available: https://www.aveva.com/en/products/intouch-hmi/

[13] K. Bourke: What is Node-RED? How Can I Use it to Create IoT Applications? December 6, 2022.
Available: https://www.realpars.com/blog/node-red

[14] OpenJS Foundation & Contributors: Node-RED [Online]. Available: https://nodered.org

[15] P. Král: Node-RED application (In Czech) [Online]. Available: https://docplayer.cz/113829298-Aplikace-node-red-zakladni-seznameni-co-je-to-node-red.html

[16] OpenJS Foundation & Contributors: Node-RED dashboard [Online].
Available: https://flows.nodered.org/node/node-red-dashboard

[17] Fischertechnik: Indexed line with 2 Machining Stations 24V DC [Online].
Available: https://www.fischertechnikwebshop.com/en-gb/fischertechnik-indexed-line-with-2-machining-stations-24v-dc-96790-en-gb

[18] Elettronew: Siemens Simatic S7-1200 1212C 8DI/6DO/2AI DC/DC/DC CPU 6ES72121AE400XB0 [Online].
Available: https://www.elettronew.com/en/automation-siemens-simatic/siemens-simatic-s7-1200-1212c-8di-6do-2ai-dc-dc-dc-cpu-6es72121ae400xb0-28941.html

[19] Siemens: Simatic S7-1200 [Online]. Available: https://www.siemens.com/global/en/products/automation/systems/industrial/plc/s7-1200.html

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A VIRTUAL REALITY SYSTEM TO TACKLE BULLYING IN SCHOOLS

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Abstract:

The aim of this study is to conduct an analysis of the possibilities of implementing new technologies (virtual or augmented reality) in addressing the problem of bullying and cyberbullying in the school environment. The possible outcome of the project should be a VR system that will increase the empathy and emotional intelligence of pupils and at the same time improve the school atmosphere in terms of bullying prevention. VR simulations can include different scenarios of bullying among pupils in school, the application of which can create an anonymised database of pupils' behaviour and use it to address the problem of bullying using appropriate artificial intelligence tools. The proposed system can help school psychologists and teachers in dealing with critical situations in schools. Pupil safety is a key aspect in school that affects the educational process and overall development of pupils.

Keywords:

Bullying, cyberbullying, virtual reality, augmented reality, VR system for bullying.

Introduction

Several studies have shown that emotional problems from bullying can persist into adulthood and cause long-term effects [1][2]. Victims of bullying often face lower self-esteem, health problems, and depression [1]. During the COVID-19 pandemic, students spent more time online, leading to increased incidents of cyberbullying. After 2020, cyberbullying rates increased and the shift to online education correlated with more incidents of cyberbullying [3][4].

Virtual reality (VR) has shown promise in addressing bullying by creating immersive experiences that foster understanding and empathy among students. Recent publications have explored virtual reality (VR) as a tool to address bullying in schools. VR can promote empathy and understanding through role-playing simulations, thereby improving the school environment [5]. Evidence suggests that immersive experiences in VR improve students' recognition of and response to bullying [6][7]. Supporting bystander intervention is key in anti-bullying efforts [4] [8]. Olweus' bullying circle identifies roles in bullying situations, highlighting the importance of defenders. The main positions of participants in the Olweus circle of bullying that can be well simulated in VR are:

1. Bully. A bully is a person who initiates and actively participates in bullying. Tends to use his or her power or strength to hurt others.
2. Followers. Individuals who actively support the bully and participate in the bullying, even if they do not initiate it themselves.
3. Supporters. Those who support bullying but do not take an active role. They may laugh or encourage the bully, but do not participate directly.

4. Passive Supporters. Persons who approve of bullying but do not openly show it. They may be silent, but their presence and inaction encourages bullying.
5. Disengaged Onlookers. Individuals who do not participate or intervene. They may think that bullying is not their problem and therefore do not get involved in the situation.
6. Possible Defenders. Those who could intervene and help the victim, but for various reasons do not. They may fear retaliation or be unsure how to intervene.
7. Defenders. People who actively intervene and try to stop bullying. They support the victim and try to resolve the situation.

VR can be further integrated into bullying prevention through a number of approaches. First, developing more immersive VR scenarios that simulate real bullying situations can increase empathy and understanding among students. Second, incorporating training programs in VR for educators can equip them with the skills to effectively identify and address bullying. Third, creating age-appropriate VR content that addresses different types of bullying (e.g., cyberbullying, physical bullying) can cater to the diverse experiences of students. Finally, involving students in the VR content development process can ensure that scenarios are relevant and resonate with their experiences, making interventions more effective. In addition, feedback from these VR sessions can be collected to identify changes in students' attitudes and behaviours towards bullying, which can be used to refine and improve the programme. As educators and researchers collaborate to develop more engaging and relevant VR content, the potential for VR to transform bullying prevention efforts in schools continues to grow.

A study showed a significant increase in cyberbullying after the pandemic, affecting more than 60% of students [4]. Effective strategies to prevent this include promoting student empathy towards the bullied and improving communication in school [8].

1 Systematically Overview of the Issues and Methodology

To analyse the feasibility of a project to prevent bullying and cyberbullying in VR settings, we used the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) methodology for a systematic review of the literature. Combinations of keywords related to "virtual reality" or "augmented reality" technologies and bullying "bullying" or "bully" were used. Due to the rapid development of VR, publications were selected from 2021 to October 2024, using the following query for all databases: ("augmented reality" OR "virtual reality") AND ("bullying" OR "bullying") with a time frame from 2020.

Only articles published in English and available in full text were included in the survey. In particular, articles relating to bullying in the context of pupils' work were included in the analysis to exclude critical situations at school level. Articles that did not contain empirical data or did not directly address the topic of VR and bullying were excluded. An initial search resulted in the identification of 74 potential articles. After removing duplicate records and applying the inclusion and exclusion criteria outlined above, 15 relevant articles remained as listed in (Tab.1).

Each of the selected articles was subjected to a detailed analysis that included data extraction of the VR technologies used, bullying, descriptive information, participants, research objectives, etc. Descriptive information included year of publication, geographic location of studies, number of participants, and of participants. The studies were divided into three main categories: bullying identification, bullying prevention, and bullying victimization. Questionnaires were also one aspect of the tracking and analysis to help better guide the direction of further research.

Table 1. Studies selected for review: author, year of publication, country, number, age of participants.

No	First autor (year)	Ref.	Country of part.	No of participants	Age of participants
1	Boboc (2024)	[5]	Various countries (combined studies)	3906 from 20 publ. avr. 195	Various studies combined
2	Yang (2024)	[9]	Taiwan	56	Fourth-grade students
3	Gayer-Anderson (2024)	[10]	United Kingdom	481	Adolescents aged 11-15 years
4	Gu (2023)	[11]	China	234	Middle and high school students
5	Liu (2023)	[12]	Taiwan	229	Eighth-grade students
6	Badger (2023)	[7]	United Kingdom	67	Female adolescents aged 11-15 years
7	López-Faican (2023)	[13]	Spain	34	Adolescents aged 12-15 years
8	Rambaree (2023)	[14]	Sweden	38	International social work students
9	Ivanov (2022)	[15]	United States	Not specified	Pilot study with a group of students
10	Fiani (2022)	[16]	United Kingdom	7	Pilot study aged 22-37 years
11	Lambe (2022)	[17]	Canada	481	Adolescents aged 11-15 years
12	Oyekoya (2021)	[18]	United States	Not specified	Focus group study
13	Barreda-Ángeles (2021)	[6]	Spain	35	Participants aged 10-12 years
14	Xue (2021)	[19]	Various countries (combined studies)	Not specified	Various studies combined (scoping review)
15	Franzen (2021)	[20]	Netherlands	45	Adolescents (24 history of bullying, 21 without)

A review study up to 2023 analysed the possibilities of using VR scenarios in conjunction with bullying [5]. The study explored the use of virtual reality and augmented reality technologies to address bullying among children and adolescent students in educational settings through a survey of 20 selected publications on the aforementioned topic of bullying.

2 Results of the Research Survey

The selection of relevant articles was followed by their analysis, in which relevant information for the research questions was extracted and synthesized: how to address the problem of bullying in school, how to use VR for students' empathy, what scenarios are appropriate in VR to achieve bullying prevention, what supportive questionnaires can monitor students' emotions, etc.

A review study up to 2023 analysed in detail the possibilities of using VR scenarios in conjunction with bullying [5]. The study explored the use of virtual reality and augmented reality technologies to address bullying among children and adolescent students in educational settings by surveying 20 selected publications similarly using the PRISMA method on the aforementioned topic of bullying. The results show that VR, in particular, has significant potential to help students understand the consequences of their actions, develop empathy, and reflect on their behaviour. VR also offers educators new ways to recognise and respond to incidents of bullying. In the following section, we mainly analyse publications that were not in the study [5].

The publication "Virtual reality or augmented reality as a tool for studying bystander behaviours in interpersonal violence" reviews 11 empirical studies using VR to simulate violent scenarios and measure bystander behaviour using the PRISMA method, with the criteria being 'avatar', 'virtual reality', 'Oculus Quest', 'augmented reality', 'bystander', 'helping behaviour' and 'witness' by 2021 [19]. They analyse the evaluation of the effectiveness of VR and AR in improving anti-bullying intervention training and examining bystander behaviour in situations of interpersonal violence. Most studies have focused on bullying in school, violence at meetings, and assaults in public. This article highlights the potential of VR to provide the most realistic and controlled setting for examining bystander behaviour, as well as recommendations for future research.

The study "Optimizing the user experience in VR-based anti-bullying education" focuses on improving anti-bullying programs based on VR user engagement scenarios and learning outcomes [15]. Key strategies include creating realistic scenarios, enabling customization, incorporating interactivity, and providing real-time feedback. A pilot study showed that optimized VR experiences increased empathy, understanding, and positive behaviour change in students' attitudes toward bullying.

The study "Investigating the non-verbal behaviour features of bullying for the development of an automatic recognition system in social virtual reality" explores the possibilities of using nonverbal behaviour to develop an automatic recognition system for detecting bullying in a social VR environment [16]. Researchers created 3D stimuli depicting bullying scenarios and conducted a pilot study with seven participants. Findings showed that nonverbal cues such as proxemics, facial expressions, gaze, and sound contribute to the perception of bullying. The study suggests that these cues can be used to develop an automatic recognition system, but further research with larger and more diverse samples to combine nonverbal cues with verbal and physiological data is needed to increase the accuracy of the system.

Developing a virtual reality environment for educational and therapeutic application to investigate psychological reactivity to bullying assessed the psychological impact of VR bullying experiences on 67 adolescent girls [7]. Participants experienced either a neutral or a hostile (bullying) VR scenario. Those in the hostile scenario reported greater negative affect and distress. The VR experience could be used in educational and therapeutic settings to increase empathy and resilience. In addition, the study highlighted how state anger and trait empathy interacted to predict defensive behaviour, highlighting the contribution of social-emotional learning in promoting defensive behaviour.

The study "Immersive virtual reality as a novel approach to investigate the association between adverse events and adolescent paranoid ideation" examines whether experiences of bullying and other interpersonal threatening events are more strongly associated with paranoid ideation in adolescents than non-interpersonal events or adverse childhood experiences [10]. Data on exposure to adverse life events and bullying were collected from 481 adolescents (aged 11-15 years).

Linear regression was used to analyze the associations between these risk factors, which were assessed through responses following experiences with the bullying VR avatar in the school cafeteria. Bullying, particularly cyberbullying, was associated with an increased prevalence of paranoid thoughts in girls than in boys.

The study "Combating bullying in school through a virtual learning model based on a multi-task experience: Assessing empathy, problem solving and self-efficacy from a multi-stakeholder perspective" looked at a scenario-based learning model in a virtual reality setting that combined participant tasks to help students raise awareness of bullying in the school environment [9]. The study compared 56 fourth-grade students in Taipei City, Taiwan, with the experimental group using a scenario-based learning model with multiple roles and the control group using a scenario-based learning model with a single role. The aim was to analyze students' behaviour in the virtual scenario-based learning model and to understand whether changes in students' experiential processes differ when playing multiple roles in relation to bullying. For this purpose, two groups of students were formed: one group of students participated in a multi-task scenario and the other group of students participated in a single-task scenario. The teaching experiment lasted 120 minutes. Pre-test and post-test questionnaires to assess the effectiveness of bullying prevention in school were developed by the researchers to ensure their expert validity. The purpose of the questionnaires was to determine how students understood and applied the concept of improving bullying awareness in school after receiving formal instruction from teachers. The test included four main themes: physical bullying, verbal bullying, relational bullying, and cyberbullying. A virtual classroom scenario recorded students' activities in the system. After the teaching experiment, both groups completed a posttest on learning outcomes, a postquestionnaire on empathy, and a posttest on problem-solving tendencies related to bullying prevention in school. This determined whether there were differences or changes between the two groups of students after the teaching experiment. Findings indicated that the virtual role-playing instructional model was more effective in promoting student empathy and significantly increased awareness of bullying in school.

To analyse the feasibility of a project to prevent bullying and cyberbullying in a VR setting, various questionnaires were also surveyed to assess various psychological and behavioural aspects in students with a focus on bullying and cyberbullying. The available questionnaires were analysed in detail so that they could be reliably used in the school setting to better understand pupils' behaviour in school. The reliability of the questionnaires was assessed using alpha values, where the interpretation of alpha values is: if the alpha is 0.70-0.80 then the questionnaire has acceptable reliability, if the alpha is 0.80-0.90 then the questionnaire has good reliability, and if the alpha is 0.90-0.95 then the questionnaire has very good reliability; a value above 0.95 may indicate redundancy of the questionnaire items. We present two types of questionnaires for bullying and cyberbullying.

Questionnaires on bullying. The questionnaires provide a detailed picture of the prevalence and characteristics of bullying, allowing for a better understanding and addressing of the problem in school. In (Tab.2), we report the name of the bullying questionnaire, the original source detailed in the reference, the number of items, the response scale, and the reliability by alpha value. The number of questionnaire items and the range of responses are chosen appropriately for the age of the pupil so that they do not pose an additional burden, yet we have obtained sufficient information.

Cyberbullying differs from traditional bullying in several keyways: it has no time or space constraints, the content posted can reach a large number of people quickly, the perpetrator can remain anonymous, and the victim has difficulty escaping. These differences make cyberbullying a particularly serious problem that requires specific approaches to prevention and resolution. Cyberbullying questionnaires focus on different aspects of cyberbullying, including frequency, types and impact on victim behaviour. In (Tab.3), we report the name of the questionnaire, the original source detailed in the reference, the number of items, the response scale, and alpha reliability.

Table 2. Bullying questionnaires.

No	Questionnaire name	Ref.	Focus	No of items	Cronbach's α
1	Child Adolescent Bullying Scale (CABS)	[21]	Evaluating young people's experiences of bullying	22	0.97
2	Revised Olweus Bully/Victim Questionnaire (OBVQ-R)	[22]	Evaluating experiences of bullying	42	McDonald ω: 0.75, 0.81
3	Adolescent Peer Relations Instrument	[23]	Assessment of peer relationships	36	0.81-0.89
4	Bullying and Exclusion Experiences Scale (BEES)	[24]	Assessment of experiences of bullying and exclusion	18	0.79-0.85

Table 3. Cyberbullying questionnaires.

No	Questionnaire name	Ref.	Focus	No of items	Cronbach's α
1	Cyberbullying and Online Aggression Survey	[25]	Assessment of cyberbullying and online aggression	18	0.79-0.97
2	The Cyberbullying in Social Media Scale	[26]	Assessment of cyberbullying on social networks	12	0.85
3	Cyberbullying Behaviour Questionnaire	[27]	Assessment of cyberbullying in working life	20	0.76
4	The Cyber Victimization Experiences and Cyber Bullying Behaviours scales	[28]	Assessment of experiences of cyberbullying and cyberbullying behaviours	15	0.85-0.89

3 Analysis of the Design of a System to Address Bullying in Schools

The design of a VR system for the issue of bullying needs to be analysed in detail in terms of designing the technological equipment, defining scenarios, scenes for the system, as well as selecting appropriate avatars, etc. Scenarios can, for example, depict bullying or cyberbullying between pupils in different ways. The main goal, which has been analysed in the previous section, is to create as realistic as possible simulations of such scenes to help pupils develop empathy with each other, to help teachers and school psychologists understand pupils better and to show ways to prevent similar conflicts in school. Many other issues need to be analysed in more detail with school psychologists.

3.1 Technological capabilities of the VR system

There are several options for a basic VR system. The first proposed technology equipment would consist of emotion tracking using the VR HTC Vive Pro Eye along with a face tracker, which provides better information to assess the user's emotions and a more realistic environment, although it requires more complex hardware. HTC Vive Pro Eye provides a resolution of 2880×1600 (1440×1600 pixels per eye) [29].

For comparison, we propose a second newer VR device using the powerful Meta Quest Pro, which has a display resolution for one eye of 1800×1920 px [30]. The Meta Quest Pro device is equipped with five infrared eye and face tracking sensors that can capture upper and lower facial movements with 120-degree accuracy. The Meta Quest Pro weighs 722 grams is comfortable for extended wear and offers color mixed reality that enhances real-world VR participation while supporting eye and face tracking.

To create realistic scenes in VR, we need to ensure a good hardware configuration, so we propose implementation based on the available HW in our lab, e.g., a computer with a Core i9 processor, 32 GB of RAM, an NVidia RTX 2070 graphics card, and a 1 TB SSD. For the actual development, it is necessary to have suitable software, such as Unity 3D or Unreal Engine. Both engines have extensive asset stores where developers can purchase or download free assets such as 3D models, textures, animations, and scripts to help develop scenarios in VR.

For stress sensing, it is advisable to use electrodermal activity (EDA) equipment, for example, we used a biosignalsplux sensor [31]. The biosignalsplux EDA sensor is designed to sense changes in skin conductance using two electrodes that are placed on the lower knuckles of the fingers of the hand (index and middle fingers). The electrodes were connected to the sensor cable of the EDA sensor. The latest EmbracePlus device [32] can also be used to sense EDA signals, which is placed on the wrist of the hand. These EDA signals are suitable for comparison with facial emotions [33].

3.2 Design of an approach to address bullying in schools

The design of the system focuses on simulating bullying in schools with the support of virtual reality (VR), so that pupils can better perceive the complexity of the whole problem in its interconnectedness. These VR scenarios include situations of bullying between pupils. The aim is to create simulations that are as realistic as possible to increase pupils' empathy and help teachers and school psychologists to better understand and deal with these situations.

The following system design and VR imaging needs to be statistically validated in order to select the most appropriate approach from the different options. Simulations include, for example, short videos and VR animations that are intended to be viewed by pupils only with parental consent. The pupil has to express briefly how he/she perceives the situation he saw in video. Alternatively, the teacher asks him/her to respond more specifically to the problem of bullying in order to better demonstrate his/her attitude. The system automatically records the conversation so that it can be transcribed into a text document with time stamps. A similar scene is then projected in VR, where the pupil's reaction is monitored by watching the face and eyes, which are stored as an avatar in a database. Finally, the school psychologist discusses the pupil's assessment with the teacher. In addition, for the pupil's assessment, he/she stores videos of the pupil's avatar, audio recordings of the pupil, questionnaire outputs anonymously in encrypted form in a comprehensive anonymous database.

D1. Anonymous response database

Pupil reactions to simulated situations are recorded and stored in an anonymous database. This database contains data on pupils' emotional and physiological reactions that are monitored during VR simulations (audio recordings, facial and eye reactions). The data are analysed using artificial intelligence (AI) to identify patterns of behaviour and reactions.

D2. Individual short interviews

In an individual interview in the presence of a school psychologist, pupils briefly answer the teacher's questions and express their feelings about critical situations. These interviews are recorded and provide qualitative data to complement the quantitative data from the questionnaires.

D3. Questionnaires

Appropriate questions should be selected for the questionnaire, which are listed in Section 2 Examples of bullying and cyberbullying questionnaires. In addition, questions may ask about feelings about the above scenarios in VR, perceptions of support from teachers and their overall perception of safety in school. Students will complete questionnaires that assess their emotional and behavioral reactions to simulated critical situations. These questionnaires provide quantitative data that is analyzed to identify patterns of pupils.

D4. Classroom discussions

After the individual interviews with the pupils have been completed and the questionnaires have been filled in, a class discussion can take place between the pupils, the teachers and the psychologist. This discussion is used to compare and evaluate each class and provides a space to share experiences and suggestions for improving the school environment in the area of bullying and cyberbullying.

D5. Comparison of results between schools

Statistical methods and machine learning that can evaluate the generated database of bullying or cyberbullying in terms of predicting certain critical student characteristics should be used. Once certain schools have been selected, it is important to interview school psychologists to obtain objective results from the database created. From the database, a representative sample of anonymous students should be selected for presentation and discussion with outside clinical and school psychology experts.

By repeating the above procedure after a certain period of time in the selected schools, it is possible to verify from the established database whether there has been a significant change in some of the anonymous pupils in the schools. These comparative studies help to verify the effectiveness of the project in addressing the problem of bullying and to identify areas for further gradual improvement.

D6. Comprehensive Pupil Assessment Database

We anticipate that repeated monitoring of pupils in selected schools will help the emerging Comprehensive Assessment Database to more effectively address critical situations in schools and in pupils' learning. This database can serve as a valuable tool for school psychologists and educators in addressing bullying and cyberbullying in the school setting.

Similar research conducted in the context of the "Early Warning of Alzheimer's Disease" project to predict neurological diseases [34]. As part of the project, we recorded people's short responses to images on a mobile phone, which were evaluated against a database using machine learning. We generalized this approach to a utility model patent using VR and physiological sensors with natural language communication (PUV 7-2024) to a prediction model using artificial intelligence.

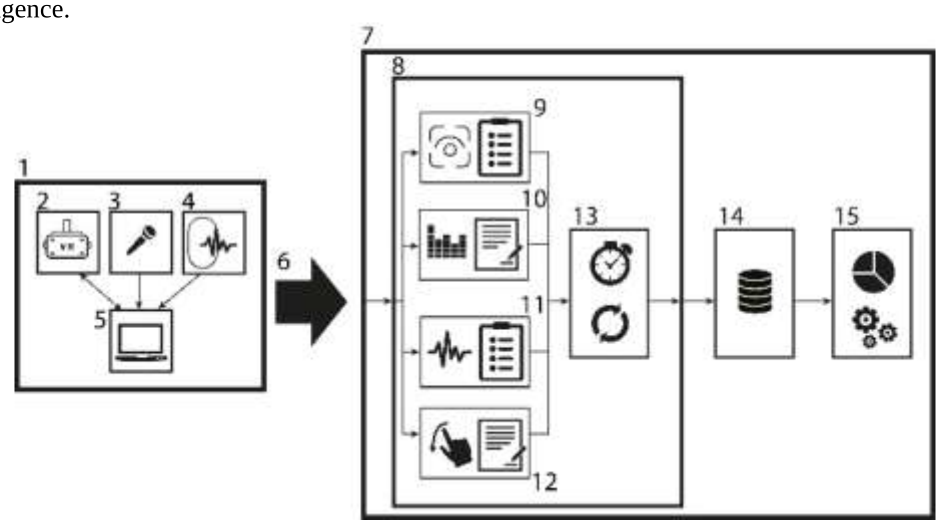

Fig.1. Devices according to the proposed technical solution for emotion analysis and speech processing in virtual reality.

The utility model of the patent is illustrated in the following (Fig.1), which schematically shows the devices and data processing in a general framework: 1 sensing device block, 2 VR device with face and eye tracking, 3 microphone, 4 physiological signal sensing device, 5 control computer, 6 data transmission, 7 execution server, 8 transcription and synchronization block, 9 facial expression and eye movement processing block, 10 audio recording block, 11 physiological signal processing block, 12 motion sensing processing block, 13 time synchronization block, 14 database created, 15 data analysis and result visualization block. Details of how the system is designed with examples are given in UV [35].

4 Discussion

The goal of the VR system is to create realistic scenarios of bullying and cyberbullying that will foster empathy in students and help teachers and psychologists understand and address these issues. Measuring empathy is a complex process that involves a variety of methods and tools. Empathy can also be measured through observation of pupils' behaviour in simulated or real situations. Teachers and school psychologists can observe how pupils react to situations such as bullying or conflicts between classmates in VR. Observations will include monitoring physiological reactions (e.g., facial expressions, eye movements, EDA signals) during VR simulations.

Initially, basic research should focus on simply creating scenarios with avatars to simulate bullying at school. The goal of the VR system would be to create realistic bullying scenarios that promote student empathy and help teachers and psychologists address these issues. The creation of a VR system for data on students' emotional and physiological reactions during VR simulations first needs to be validated on a smaller sample of, say, 100 students, in order to ascertain the analysis and determine the continuation of the applied research. Store this data in an anonymous database and analyze it using machine learning to identify patterns of behaviour and reactions.

Individual interviews with students can provide deeper insights into their empathic abilities. During these interviews, teachers can ask questions about specific situations and analyse how pupils perceive and react to the emotions of others. The questionnaires will be used to assess pupils and create a comprehensive assessment database.

This approach combines advanced virtual reality technology with psychological assessment methods to create a comprehensive system to address bullying in schools. It emphasizes the importance of realistic simulations, data analysis, and ongoing monitoring to improve the school environment and support students.

The synthesis of experiences in the cited cross-country studies enriches the research with a comprehensive view of bullying and the effectiveness of using VR, with an emphasis on cultural sensitivity and the development of inclusive programs. Bullying is a global problem and understanding it from a multicultural perspective helps to design interventions that can be implemented globally. Behaviours and responses to bullying can vary considerably between cultures. Insights from different cultural contexts can inform the development of universal anti-bullying programmes that are inclusive and effective for a wide range of participants.

Conclusion

Studies from different countries show how to help understand the problem of bullying in schools and tailor measures accordingly. The above research shows the potential of virtual reality as a tool for preventing bullying or cyberbullying in schools. By creating a suitable anonymous database from pupils' reactions, emotions and biosignals and analyzing it for critical situations, machine learning can help identify subtle nuances in reactions. This would result in a school environment monitoring system to deal with critical situations in schools and also secondarily improve empathy and emotional intelligence of students and hence mental health of students in schools. The diversity of solutions to the problems of bullying, cyberbullying in schools encourages international cooperation which would contribute to more effective solutions to prevent critical situations in schools.

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References

[1] Olweus, D. (1994). Bullying at School: Basic Facts and Effects of a School Based Intervention Program. Child. Psychol. Psychiat 35, 1171-1190. doi:10.1111/ j.1469-7610.1994.tb01229.x

[2] Nansel, T. R., Overpeck, M., Pilla, R. S., Ruan, W. J., Simons-Morton, B. and Scheidt, P. (2001). Bullying Behaviors Among US Youth, Prevalence and Association With Psychosocial Adjustment, Jama 285, 2094-2100. doi:10.1001/jama.285.16.2094

[3] Zhu C, Huang S, Evans R and Zhang W (2021) Cyberbullying Among Adolescents and Children: A Comprehensive Review of the Global Situation, Risk Factors, and Preventive Measures. Front. Public Health 9:634909. doi: 10.3389/fpubh.2021.634909

[4] António, R., Guerra, R. & Moleiro, C. Cyberbullying during COVID-19 lockdowns: prevalence, predictors, and outcomes for youth. Curr Psychol 43, 1067-1083 (2024). https://doi.org/10.1007/s12144-023-04394-7 .

[5] Boboc, R.G., Damaševičius, R. Confronting bullying in the digital age: Role of Extended Reality. Educ Inf Technol 29, 1-30 (2024). https://doi.org/10.1007/s10639-024-12557-7

[6] Barreda-Ángeles, M., et al. (2021). Development and experimental validation of a dataset of 360°-videos for facilitating school-based bullying prevention programs. Computers & Education, 168, 1-14. https://doi.org/10.1016/j.compedu.2021.104196

[7] Badger, J. R., Rovira, A., Freeman, D., & Bowes, L. (2023). Developing a virtual reality environment for educational and therapeutic application to investigate psychological reactivity to bullying. Virtual Reality, 27(3), 2623-2632. https://doi.org/10.1007/s10055-023-00829-5

[8] Babvey, P., Capela, F., Cappa, C., Lipizzi, C., Petrowski, N., & Ramirez-Marquez, J. (2021). Using social media data for assessing children's exposure to violence during the COVID-19 pandemic. Child Abuse & Neglect, 104747. https://doi.org/10.1016/j.chiabu.2020.104747

[9] Yang, K.-H., & Lu, Y. (2024). Combating school bullying through multi-role experience-based virtual scenario learning model. Heliyon, 10(10), e31044. https://doi.org/10.1016/j.heliyon.2024.31044

[10] Gayer-Anderson, C., Knowles, G., Beards, S., Turner, A., Stanyon, D., Davis, S., Blakey, R., Lowis, K., Dorn, L., Ofori, A., Rus-Calafell, M., Morgan, C., & Valmaggia, L. (2024). Immersive virtual reality as a novel approach to investigate the association between adverse events and adolescent paranoid ideation. Social Psychiatry and Psychiatric Epidemiology, 59(6), 1-19. https://doi.org/10.1007/s00127-024-02701-6

[11] Gu, X., Li, S., Yi, K., Yang, X., Liu, H., & Wang, G. (2023). Role-Exchange Playing: An Exploration of Role-Playing Effects for Anti-Bullying in Immersive Virtual Environments. IEEE Transactions on Visualization and Computer Graphics, 29(10), 1-14. https://doi.org/10.1109/TVCG.2023.3245678

[12] Liu, Y.-L., Chang, C.-Y., & Wang, C.-Y. (2023). Using VR to investigate bystander behavior and the motivational factors in school bullying. Computers & Education, 194, 1-14. https://doi.org/10.1016/j.compedu.2022.104696

[13] López-Faican, L., & Jaen, J. (2023). Design and evaluation of an augmented reality cyberphysical game for the development of empathic abilities. International Journal of Human-Computer Studies, 176, 1-18. https://doi.org/10.1016/j.ijhcs.2023.103041

[14] Rambaree, K., Nässén, N., Holmberg, J., & Fransson, G. (2023). Enhancing cultural empathy in international social work education through virtual reality. Education Sciences, 13(5), 507. https://doi.org/10.3390/educsci13050507

[15] Ivanov, L. (2022). Optimizing the user experience in VR-based anti-bullying education. Adjunct Proceedings of the 30th ACM Conference on User Modeling, Adaptation and Personalization, 1-10. https://doi.org/10.1145/3511047.3536406.

[16] Fiani, C., & Marsella, S. (2022). Investigating the non-verbal behavior features of bullying for the development of an automatic recognition system in social virtual reality. Computers in Human Behavior, 130, 1-12. https://doi.org/10.1016/j.chb.2022.107206

[17] Lambe, S., & Craig, W. (2022). Immersive virtual reality as a novel approach to investigate the association between adverse events and adolescent paranoid ideation. Journal of Adolescence, 94, 1-15. https://doi.org/10.1016/j.adolescence. 2022.103567

[18] Oyekoya O, Urbanski J, Shynkar Y, Baksh A and Etsaghara M (2021) Exploring First-Person Perspectives in Designing a Role-Playing VR Simulation for Bullying Prevention: A Focus Group Study. Front. Virtual Real. 2:672003. doi: 10.3389/frvir.2021.672003

[19] Xue, J., et al. (2021). Virtual reality or augmented reality as a tool for studying bystander behaviors in interpersonal violence: A scoping review. Journal of Interpersonal Violence, 36(15-16), 1-20. https://doi.org/10.1177/0886260518799456

[20] Franzen, M., et al. (2021). Victims of Bullying: Emotion Recognition and Understanding. Journal of School Psychology, 84, 1-12. https://doi.org/10.1016/j.jsp.2021.104567

[21] Strout, T. D., Vessey, J. A., DiFazio, R. L., & Ludlow, L. H. (2018). The Child Adolescent Bullying Scale (CABS): Psychometric evaluation of a new measure. Research in nursing & health, 41(3), 252-264. https://doi.org/10.1002/nur.21871

[22] Gaete, J., Valenzuela, D., Godoy, M. I., Rojas-Barahona, C. A., Salmivalli, C., & Araya, R. (2021). Validation of the Revised Olweus Bully/Victim Questionnaire (OBVQ-R) Among Adolescents in Chile. Frontiers in Psychology, 12, 578661. https://doi.org/10.3389/fpsyg.2021.578661

[23] Parada, R. (2000). Adolescent Peer Relations Instrument: A theoretical and empirical basis for the measurement of participant roles in bullying and victimization of adolescence: An interim test manual and a research monograph. Publication Unit, Self-concept Enhancement and Learning Facilitation (SELF) Research Centre, University of Western Sydney.

[24] Deighton, R.M., & Murphy, A. (2024). Development and validation of a new measure of school-age bullying experiences for adults: the Bullying and Exclusion Experiences Scale (BEES). Discov Psychol, 4, 38. https://doi.org/10.1007/s44202-024-00129-2

[25] Hinduja, S., & Patchin, J. W. (2015). Bullying Beyond the Schoolyard: Preventing and Responding to Cyberbullying (2nd edition). Sage Publications.

[26] Audinia, S., et al. (2023). The Development of Cyberbullying in Social Media Scale. Jurnal Pengukuran Psikologi dan Pendidikan Indonesia, 12(1), 80-92. https://doi.org/10.15408/jp3i.v12i1.24142

[27] Jönsson, S., Muhonen, T., Forssell, R. C., & Bäckström, M. (2017). Assessing Exposure to Bullying through Digital Devices in Working Life: Two Versions of a Cyberbullying Questionnaire (CBQ). Psychology, 8, 477-494. https://doi.org/10.4236/psych.2017.83030

[28] Betts, L. R., & Spenser, K. A. (2017). Developing the Cyber Victimization Experiences and Cyberbullying Behaviors Scales. The Journal of Genetic Psychology, 178(3), 147-164. https://doi.org/10.1080/00221325.2017.1295222

[29] Vive Developers, "Eye and Facial Tracking SDK," (2021). Online. Available: https://developer.vive.com/resources/vive-sense/eye-and-facial-tracking-sdk/. [Accessed: Dec. 13, 2024].

[30] HTC Vive Pro vs Meta Quest Pro. (2023). Online. https://versus.com/en/htc-vive-pro-vs-meta-quest-pro. [Accessed: 16-Nov-2024].

[31] Electrodermal Activity (EDA) Sensor User Manual, (2021). Online. https://www.creact.co.jp/measure/bio/bitalino/file/biosignalsplux-Electrodermal-Activity-EDA-User-Manual-1.pdf. [Accessed: 16-Nov-2024].

[32] Empatica, "EmbracePlus" Inc. (2024). Online. Available: https://www.empatica.com/en-gb/research/e4/. [Accessed: Oct. 12, 2024].

[33] Büscher, R., Winkler, T., Mocellin, J. et al. (2024). Passive Sensing for the Prediction of Suicidal Thoughts and Behaviors: A Systematic Review and Recommendations for Future Research, (2024). https://doi.org/10.21203/rs.3.rs-3494525/v1

[34] Rusko, M., Sabo, R., Trnka, M., Zimmermann, A., Malaschitz, R., Ružický, E., . . . Škorvánek, M. (2024). Slovak database of speech affected by neurodegenerative diseases. Scientific Data, 11(1), 1320. doi:10.1038/s41597-024-04171-6

[35] Bulletin of Industrial Property Office of the SR (in Slovak) “Vestník ÚPV SR," [Online]. Available: https://www.indprop.gov.sk/produkty-a-sluzby/produkty-uradu/vestnik-upv-sr. [Accessed: 16-Nov-2024]

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INTERFERENCE IN OFDM SYSTEMS AND NETWORKS

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Abstract:

In this paper we present an overview of various kinds of interference, that arise in the Orthogonal Frequency-Domain Multiplexing (OFDM)-based digital communications systems at the physical layer. Inter-symbol, inter-block, inter-carrier interference types are described in detail, valid for any OFDM transmission, along with Inter-cell interference specific to cellular networks. A survey of various communication disruptions techniques is presented – primarily focusing on intentional interference – jamming. Furthermore, we present a survey of modulation techniques that expand on the OFDM and may be considered viable candidates for modulation in the future 6G cellular networks.

Keywords:

OFDM, interference, jamming, 6G modulation candidates.

Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is the most commonly used wide-band modulation technique, present in nearly all modern high bandwidth communication systems and standards. Employed reliably in Wi-Fi networks, it serves reliably at the physical layer as modulation in IEEE 802.11a, g, n, ac, ax, as well as the latest iteration – IEEE802.11be [1], also known as Wi-Fi 7. Given its high spectral effectivity and resilience to multipath fading occurring in terrestrial transmissions, OFDM has been the modulation of choice also in the context of cellular networks for some time now: the time-proven 4G Long Term Evolution (LTE) [2] as well as the currently deployed 5G networks [3] are both based on the OFDM modulation. OFDM serves also in the wired digital subscriber lines standard DOCSIS [4], and even in the proprietary Starlink LEO satellite constellation (The specification is not publicly available, but measurements are [5]). Furthermore, various modulation schemes are currently evolving from the OFDM, and are subject of intense theoretical research, evaluation and debate, with several potential candidate technologies contemplated for utilization in the future 3GPP 6G standards releases on the horizon 2030.

However, OFDM is also susceptible to various forms of interference, occurring naturally or as a result of intentional disruption effort: jamming, where malicious actors disrupt communication by emitting interference signals. To counter such threats, various techniques of OFDM modulation fortifications are emerging. The analysis of intentional disruption techniques is an important input for future standardization. The 3GPP standard 5G New Radio (NR) [4] is currently being deployed on a global scale and can be viewed as a direct evolution of the OFDM-based transmission defined for 4G.

The primary security measure in wireless networks is the encryption of the over-the-air messages, providing protection from eavesdropping and, as described in later sections, also some indirect attack resistance.

Since the time of the failed and completely broken Wired Equivalent Privacy (WEP) attempt, encryption is heavily employed in Wi-Fi. The modern Wi-Fi Protected Access (WPA) [6] security framework is currently in its third generation with Perfect Forward Secrecy (PFS) as an integral feature [7]. In the context of cellular networks, serious effort to encrypt the control information sent out by the base station has been put already into the 4G standard, while some vital pieces of information, that can be used by the attacker to disrupt network operation, are transmitted out in plaintext. On top of that, some control messages are not protected by a cryptographic Message Integrity Check (MIC), giving a potential attacker the opportunity to falsify them. Most of these weak points have been addressed in the 5G NR specifications with one important caveat: to accelerate the deployment of 5G, two potential modes of operation have been standardized: the Standalone Application (SA) [8], also called the true 5G, is the desired variety in which the 5G base station, known as the gNodeB, is connected to the 5G core network. The Non-Standalone Application (NSA) is a backward-compatibility measure designed as an intermediate step to integrate newly deployed gNodeB stations into existing 4G network: The 5G gNodeB provides fast data-frames transmission to the UE, while the control messages are all handled by the previous-generation cooperating eNodeB [9]. Most of the currently deployed 5G networks in the European union operate in a NSA mode, with full SA to be implemented as soon as possible. Based on this insight, when analyzing the vulnerability of a 5G NSA network, many of the weaknesses identified for 4G networks are still valid.

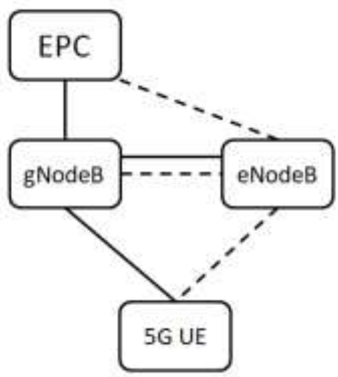

Fig.1. NSA 5G network operation, option 3x [9]: The 5G gNodeB provides fast data-frames transmission to the UE (solid line), while the control messages (dashed line) are all handled by the previous-generation cooperating eNodeB.

The paper is organized as follows: the next section gives a brief recap of the principles of wireless OFDM transmission in the multipath fading channel environment of cellular networks. The second section describes various forms of "naturally" occurring interference – interference inherent to the OFDM design. The third section then provides a survey of recent literature – the current state of published research on topics of unintentional interference. Intentional interference also known as jamming, is surveyed in the fourth section. The fifth section then provides an overview of the potential OFDM modifications – evolution steps, that may be considered as candidates for modulation techniques in the future 6G specifications. The last section then concludes the paper.

1 OFDM Principles

The basic principle of OFDM is the demultiplexing of a high-rate data stream to many low-rate streams in the transmitter, with each of the substreams modulated – assigned a prototype in digital domain (signal space) and placed on a separate subcarrier frequency. The N subcarriers are spaced uniformly in the frequency domain with distance $\Delta f = 1/T$, where T is the OFDM symbol duration. This subcarrier spacing provides for the orthogonality of the subcarriers as illustrated in (Fig.2): The center frequency of each subcarrier is simultaneously exactly the zero-crossing point of the frequency responses of all the other subcarriers, making the set of discrete frequencies $f_i \in \{k\Delta f + f_0\}$, $k = \{0,1,\ldots\ N-1\}$ points of zero interference. The set of N orthogonally spaced subchannels is then multiplexed together to form the resulting, potentially complex, OFDM prototype. Inverse Discreet Fourier Transform (IDFT) is utilized for practical implementation of this process along with converting the frequency domain digital prototype samples to time domain.

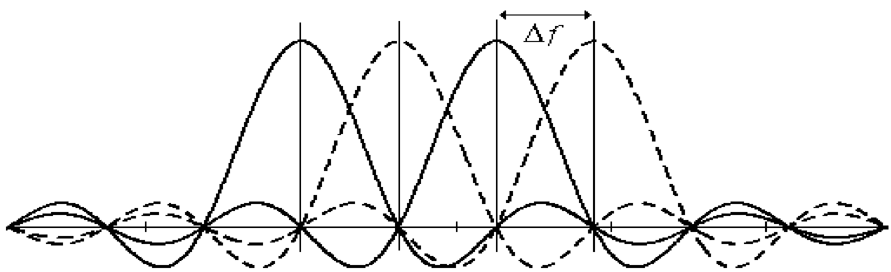

Fig.2. Orthogonal subcarrier spacing in frequency domain [10].

A unitary version of the IDFT given by (1) may be chosen to preserve the signal energy.

$$x_n = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_k \cdot e^{\frac{j2\pi}{N}nk} \qquad n,k=0,\ldots,N-1 \tag{1}$$

After the conversion to time domain, the block of samples of the OFDM symbol is prepended by its own subblock containing some small fraction (1/32 to 1/4) [11] of the symbol samples. This repetition of some of the samples is called the Cyclic Prefix (CP) Insertion (CPI) and together with an inverse operation in the receiver – the CP Removal (CPR) it serves the important function of facilitating a multipath channel distortion equalization. The effect of the CPI on the data samples is shown in (Fig.3) with the CP length expressed in time denoted as T_g, the useful symbol time T_u, and the final transmitted OFDM symbol duration $T = T_g + T_u$. Alternatively the CP length may be expressed in the number of samples: If the number of useful samples is N, then the total number of the symbol with CP may be denoted N_c.

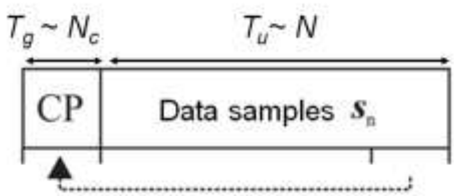

Fig.3. The OFDM symbol (block of samples) prolonged by cyclic prefix insertion.

In a wireless transmission, the primary effects negatively effecting the signal are reflection, refraction and scattering [10]. As shown in (Fig.4), several delayed and attenuated copies of the transmitter signal arrive at the receiver antenna where they combine – usually in a destructive way.

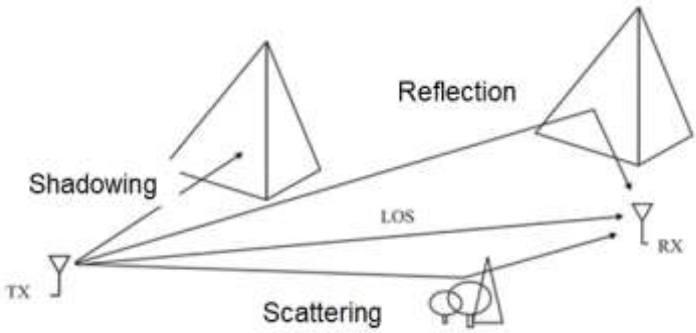

Fig.4. Multipath propagation of a wireless signal in a terrestrial channel [10].

The digital data transmission over a multipath channel may be simply modelled by a convolution with channel impulse response h in the time domain given by (2), and addition of an Additive White Gaussian Noise (AWGN) with power σ^2.

$$r_n = \sum_{m=1}^{\nu} h_m \times t_{n-m+1}\ , \quad n = 1,\dots,N_C + \nu - 1 \tag{2}$$

A simplified OFDM system is shown in (Fig.5) together with the multipath channel model. While the Analog/Digital and Digital/Analog converter circuits are necessary, the focus of most of the signal processing described in literature lies in the digital domain. The ECC block presents the Error Control Coding – adding redundancy to data in order to protect the data against errors introduced by the channel, while the corresponding A-Posteriori Probability (APP) block in the receiver denotes a soft-input ECC decoder based on posterior probabilities. The Constellation Mapping (CM) block performs the signal space mapping described above and the Discrete Fourier Transform (DFT) block in the receiver transforms the received OFDM block back to frequency domain. The noisy samples then enter the Frequency Domain Equalization (FDE), after which the projections to the signal space are used as input to the ECC decoder.

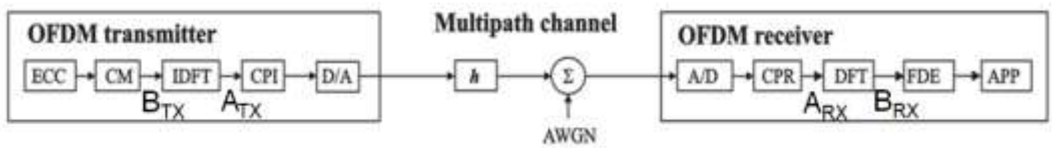

Fig.5. OFDM transmission model with multipath channel [12].

The cyclic prefix insertion in the transmitter, and its removal in the receiver converts the linear convolution that actually takes place in the channel (2) to a cyclic convolution defined by (3) effectively observable between the interfaces A_{TX} and A_{RX} shown in (Fig.5).

$$r_n = \sum_{m=1}^{\nu} h_m \times s_{[(n-m) \bmod N]+1}, \quad n = 1,\ldots,N \tag{3}$$

By utilizing the DFT properties, the cyclic convolution of the discrete-time domain vectors translates to simple per-component multiplication of their Fourier transforms in the discrete-frequency digital domain, so the cascade of blocks shown in (Fig.5) between interfaces B_{TX} and B_{RX} can be expressed as a set of N independent simple per-sample multiplications. This may be written by (4) where the k is the index in the discrete-frequency domain $H(k)$ is the channel frequency response, the $S(k)$ is the transmitted OFDM symbol – a block of complex numbers of length N, and $R(k)$ is the received block of distorted and noisy samples at the input of the FDE block in the receiver.

$$R(k) = H(k) \cdot S(k), \quad k = 0,\ldots,N-1 \tag{4}$$

Given a channel frequency response estimates $H(k)$, the equalization performed in the frequency domain described equally simply by per-sample division as shown in (5):

$$\hat{S}(k) = \frac{R(k)}{\hat{H}(k)}, \quad k = 0,\ldots,N-1 \tag{5}$$

The computational simplicity of the frequency domain equalization of the multipath channel distortion is the primary reason for the success of the OFDM modulation, allowing its ubiquitous presence in almost all modern wideband digital communications systems.

2 Interference in OFDM Transmission

The simplified model of an OFDM transmission presented in the previous section omits the various conditions and interference types that negatively affect an OFDM system. Further blocks need to be added to the simplified system model shown in (Fig.5), in order to mitigate various types of interference and other negative channel effects. Some of them explained in later sections. Let us now summarize the various interference types that negatively affect OFDM transmission.

Inter-Symbol and Inter-Block Interference

One of the effects of the linear convolution of the transmitted OFDM symbol $S(n)$ by the channel impulse response $H(n)$ is the prolonging of the transmitted block: As defined in (2): if the length of the transmitted block $S(n)$ is N_c and the length of $H(n)$ is ν, then the length of the resulting received block is $N_c + \nu - 1$. As the OFDM symbols are transmitted serially, some samples of the received symbol begin to overlap with the next symbol. This effect, when expressed in discrete-time, when the OFDM symbol is represented by a vector of complex numbers, is called the Inter-Block Interference (IBI). When viewing the OFDM in the continuous time as a waveform, this effect is called Inter-Symbol Interference (ISI). As described in the next section, this is somewhat confusing, and a more precise term: Inter-OFDM-Symbol Interference (IOSI) would be more suitable. The general practice in literature is the usage of the term ISI, while also using the terms ISI and IBI interchangeably.

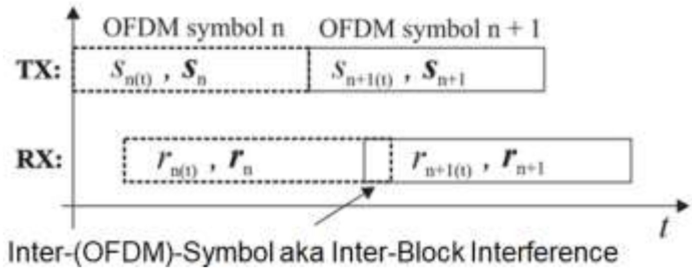

Fig.6. Inter-(OFDM)-Symbol and Inter-Block Interference
as a consequence of linear channel convolution [12].

Inter-Symbol Interference

As described before, the CP prefix insertion and removal in OFDM serves the important function of removal of the Inter-Block Interference. This is illustrated in more detail in (Fig.7), that shows that the transmitted OFDM symbols with redundant CP are indeed affected by the IBI, but as long as the length of the CP is longer than the channel maximum excess delay, only the CP is affected, and the useful part of the OFDM symbol remains IBI-free. The condition of CP length being longer than the channel maximum excess delay is fundamental for successful equalization an OFDM the receiver.

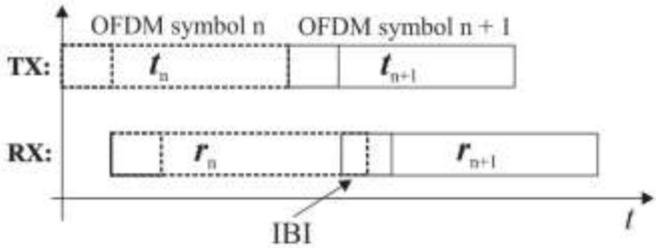

Fig.7. Transmission of OFDM symbols with redundant Cyclic Prefix:
IBI affects only the CP samples, which are discarded in the receiver [12].

After the conversion of the linear channel convolution to circular convolution defined in (3), the IBI goes away, but each of the received samples within one OFDM block is still a linear combination of several transmitted samples. Such linear convolution may be modelled by a simple matrix multiplication with a circulant channel convolution matrix $\mathbf{H_c}$:

$$\mathbf{H_c} = \begin{bmatrix} h_1 & 0 & \dots & h_\nu & \dots & h_2 \\ h_2 & h_1 & 0 & 0 & \ddots & \vdots \\ \vdots & h_2 & h_1 & \ddots & 0 & h_\nu \\ h_\nu & \vdots & h_2 & \ddots & 0 & 0 \\ 0 & \ddots & \vdots & \ddots & h_1 & 0 \\ \vdots & 0 & h_\nu & \dots & h_2 & h_1 \end{bmatrix} \quad (6)$$

This effect is again known as Inter-Symbol Interference (ISI) and is qualitatively different from the IOSI defined in the previous section in that all the received samples originate with the same transmitted OFDM symbol/block. In literature the term ISI is used interchangeably in both situations and the reader must be aware of the context in order to understand which effect is actually being described.

Inter-Carrier Interference

The interference type with the most disastrous effect on the transmissions Bit Error Ratio (BER) is without doubt the Inter Carrier Interference (ICI). Again, the nomenclature is imprecise, since what is actually going on in this case is the loss of orthogonality between subcarriers, belonging to the same multiplexed set of substreams of one transmission. The more precise term should therefore be Inter-SubCarrier Interference (ISCI), but ICI is the dominant term in literature. As illustrated in (Fig.2), in an ideal OFDM system subcarriers are orthogonal to each other, meaning their waveforms do not interfere at the select discrete subcarrier frequencies, even as they otherwise completely overlap in the frequency domain. In a practical system, the subcarrier may be slightly shifted for various reasons: for instance the local oscillator in the receiver analog frontend may have a slightly different frequency than the oscillator in the transmitter. This is denoted as frequency offset an illustrated in (Fig.8), where all the subcarrier frequencies are shifted by some small Δf. As illustrated, the spectrum of one subcarrier is now perturbed by the sum of the spectra of many different subcarriers at this frequency point, not just the directly adjacent ones: each of the discrete frequency points in (Fig.8) consists of the sum of 4 different values where the largest value represents the desired signal, and the sum of all the others represents harmful interference. Even a small frequency shifts cause a substantial accumulation in this sum and a subsequent drop in the perceived Signal to Noise Ratio (SNR), dramatically increasing the error probability. In wideband systems, the total channel width is in the order of tens of MHz (the typical LTE channel width is 10 MHz, while the classic Wi-Fi channel is 20 MHz wide). Much higher values are permitted in more recent version of these standard with IEEE 802.11 be specifying channels up to 320 MHz wide [1]. The problem is that the subcarrier spacing is much tighter than that, e.g. in the LTE, it is only 15 kHz, which is, comparing to the channel bandwidth, several orders of magnitude smaller. For such a small subcarrier spacing, even a few kHz of frequency offset, when unmitigated, represents a disastrous ICI.

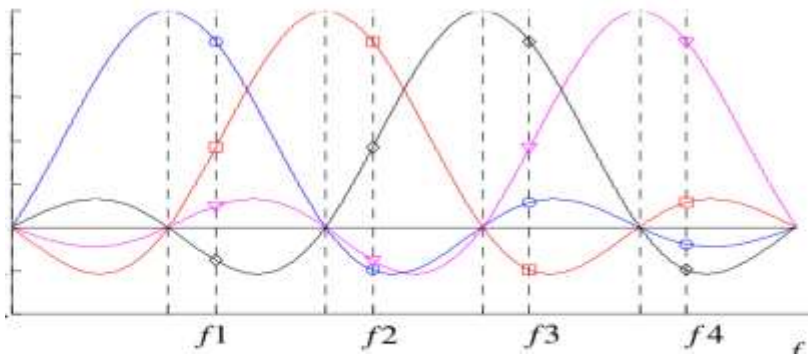

Fig.8. The loss of orthogonality between subcarriers because of RX frequency offset [13].

Even though the local oscillator offset may be successfully eliminated by a Phase-Locked Loop (PLL) circuitry in the receiver, other effect, such as the Doppler shift or amplifier nonlinearities may introduce further spurious frequency components together with the another complication: the frequency offset is not constant over the systems bandwidth. The ICI also arises if the fundamental condition for FDE: the CP length exceeding the channel excess delay, is not satisfied.

Inter-Cell and Intra-Cell Interference

Mobile communications networks are called cellular networks because of the fact that the area of interest is divided into a grid of non-overlapping cells – each with a base station in the middle, covering a carefully selected subarea. The cells are large in diameter in case of sparsely populated rural areas, and very small in dense urban centers. A typical diagram of part of cellular network is shown in (Fig.9). While in reality the actual cells may take on complex shapes, reflecting the actual topology – the shapes and sizes of the buildings in case of a urban setting, the cells are usually drawn as a hexagonal grid for simplicity. As shown further in (Fig.9) using this approximation each cell borders on 6 other cells. While the signal reception is good near the cell center, as the UE moves between cells, it must spend some time in the cell border area, where the signals from two, or even three base station overlap. The UE is usually connected to only one serving base station, so the signal from neighboring BSs presents an interference – the Inter-cell interference. In contrast to the inter-cell interference the intra-cell interference is used as an umbrella term for various other types of interference occurring within one cell as described in previous sections.

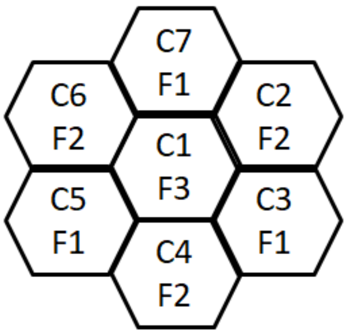

Fig.9. The basic structure of a cellular network with Frequency Reuse factor 3: using F1, F2, F3.

Several methods of dealing with this type of interference are applied in various cellular networks generations with one of the oldest – the Frequency Reuse Factor 3 [14] shown in (Fig.9): the available bandwidth is divided in three different subbands, while each of the cell uses one of the subbands with no two adjacent cells using the same subband. In this way, the inter-cell interference is successfully eliminated for the price of reducing the available frequency bandwidth by a factor of 3. Given the astronomical prices the network operators pay for the licensed bands, this price is too high to pay and one of the specifics of the OFDM is the ability to implement interference coordination strategies like Coordinated Multi-Point (CoMP) in a Single Frequency Network (SFN) [15] where even the neighboring cells can use the same frequency, but the base stations synchronize their OFDM transmission in such a way, that the UE receives several copies of the same OFDM symbol, originating from different base stations. These copies then don't interfere, they combine constructively, and if the time difference between the first and the last received copy doesn't exceed the Cyclic Prefix length, the OFDM receiver is in theory able to decode these signals as a standard multipath channel using the FDE described before. Furthermore, this coordinated transmission, denoted depending on the context as spatial- or antenna- diversity, may actually turn the interference into a benefit to the transmission: if the signal from one BS is temporarily overshadowed by some obstacle, the signals from neighboring cells may happen to coincide with a better path with less attenuation.

Self-, Cross Link- and Adjacent Channel- Interference

The problem of self-interference arises in situations when the collocated transmitter and receiver both transmit and receive at the same time. This may occur in various scenarios but the most likely is the operation of a base station in cellular networks. In older Frequency Division Duplex (FDD) specifications the downlink (DL) and uplink (UL) directions (to and from the UE) are separated by using different frequency bands, while in more recent 5G NR Phase 2 systems the Time Division Duplex (TDD) becomes dominant (depending on the exact band used). In TDD the UL and DL directions use both the same frequency band, but not simultaneously – at any given time transmission occurs in only one of the directions. The most recent advancements, contemplated for deployment in the 5G-Advanced, present a new scheme for a full duplex operation: the Subband non-overlapping Full Duplex (SBFD) [16]. In this duplex mode, it is possible to receive and transmit at the same time within the same band, but the band is further partitioned to subbands. (Fig.10) shows a standard OFDM DL resource grid: a grid of time- and frequency- slots, as used in the LTE along with some terminology: the Resource Element (RE) is the smallest unit and consists of one subcarrier with duration of one OFDM symbol. The REs are grouped into larger groups – rectangular Resource Blocks (RB) to be allocated for mapping of user data. Similar structure, differing only in exact parameters values (aka numerology) is valid for 5G. In the SBFD context, dynamically created subbands may be allocated within this grid and may be used for UL transmission.

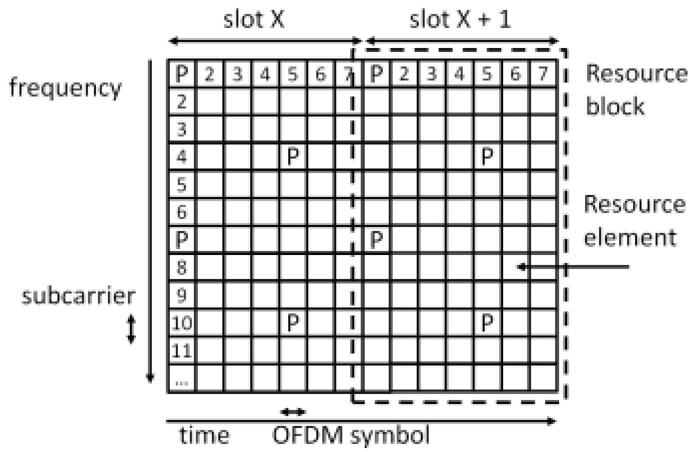

Fig.10. OFDM resource grid in LTE.

Selected subbands may be then dynamically allocated for UL transmission, while the rest of the subbands carry downlink data. The method is then a combination of FDD and TDD, with the advantage of much finer granularity for subband selection and increased flexibility for UL and DL resources allocation [17]. However, it also (re-)introduces another interference types: The *Self-Interference* is the interference of the transmitter, whose output radiated field interferes with the received signals from the opposite side of the wireless link. It is usually a problem occurring at the base station, since it uses a large output power and signal arriving from a connected UE is much weaker. In a similar fashion, the *Cross-Link Interference* (CLI) denotes such potential interference between DL and UL signals from different UEs or coming from a different cell.

An in principle somewhat similar type of interference is the *Adjacent Channel Interference* (ACI) described in [18] as an interference that arises from the fact that one of the inherent drawbacks of OFDM is the high Out-Of-Band (OOB) radiation.

This stems from the construction of the OFDM prototype by setting the complex amplitudes of a continuous set of subcarriers as shown on (Fig.11), which can be understood as using a rectangular window, which causes a significant fraction of energy overflowing from modulated subcarriers to adjacent frequency bins.

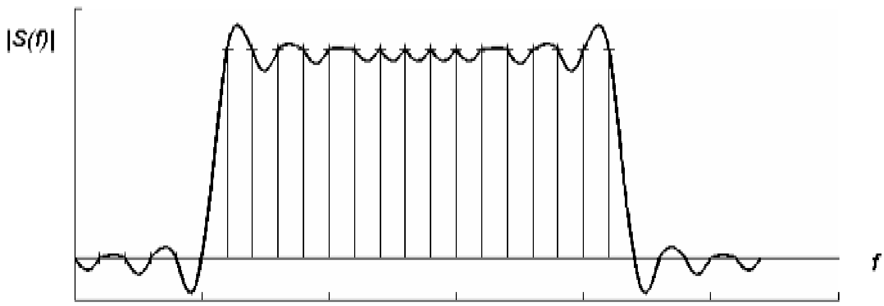

Fig.11. Setting the values of OFDM subcarriers in frequency domain may be viewed as using a rectangular window.

A common means of dealing with this interference is to set some fraction of the subcarriers at the edges of the band to zero as a guard band. On the other hand, this approach introduces waste of precious frequency bandwidth, so alternative method of subcarrier-wise filtering and Filter-Bank MultiCarrier (FBMC) implementation may be used [19].

3 OFDM Interference & Mitigation Survey

Since the Inter-Carrier Interference is the most destructive form of interference, it has been the subject of intense research over the years with some limited success achieved in the form various ICI-Self Cancellation (ICISC) designs. All based on the observation, that adjacent subcarriers, if they are modulated with opposite polarity symbols, can be used in the receiver to cancel out each other’s interference contribution. This has been described in literature and expanded on in the form of introduction of Polynomial Cancellation Coding (PCC) [20], Symmetrical Cancellation Coding (SCC) [21] and Conjugate Cancellation (CC) [22]. All of these ICI cancellation schemes share a significant drawback: they may all be understood as some form of repetition coding with low rate around $R = 1/2$. Therefore, they effectively reduce the useful data rate (and OFDM spectral effectivity) to a half. [23] represents a more recent significant evolution of the interference cancellation by introducing two novel ICI cancellation schemes: one based on a especially designed data scrambling algorithm, other based on interleaving the complex subcarrier amplitudes in the frequency domain prior to the IFFT. Both proposed schemes do not introduce any extra redundancy, while providing some ICI cancellation capabilities presenting an interesting compromise between ICI cancelling and added complexity.

Similarly [24] describes a method for mitigation of the ICI in the context of OFDM communication with passive RF tags. These simple devices have no power source and rely on reflecting and altering the received OFDM signal according to the information to be transmitted. This is known as backscattering and has been traditionally used with simpler modulations such as ON-OFF keying. The novel usage of backscattering of a complex OFDM transmission has been suggested only recently in [25] with the limitations arising from the spectral shift occurring because of the backscattering process, causing ICI. [25] then proposes an interference cancellation scheme that utilizes unused OFDM subcarriers for generating of the cancellation signal for ICI suppression.

[26] describes an ICI mitigation scheme in the context of MIMO-equipped OFDM systems employing advanced signal processing in the form of Space-Time Line Code (STLC) or Space-Time Frequency Code (STFC) [27], that enable the encoding of transmitted symbols using the Channel State Information (CSI) in the transmitter, while decoding using a simple linear combination with only partial CSI in the receiver, achieving full rate together with full diversity. The weakness of STLC/SFLC-OFDM systems lies in the sensitivity to ICI caused by the Doppler shift in high-mobility scenarios. [27] then reuses the principle of the ICI- Self Cancellation defined in [28] that manipulates the symbols assigned to adjacent subcarriers in order to cancel out the ICI. Specifically, the data bits are modulated in such a way, that adjacent subcarriers carry symbols with opposing values.

A complementary scheme for ICI mitigation in high-mobility setting is described in [29] again in the context of MIMO-OFDM systems, while deriving a custom method of signal detection based on the Expectation Propagation (EP) method described in [30]. The proposed new method based on Bayesian estimation [31] performs data estimation assuming the perfect Channel State Information (CSI) is available in the receiver, and also suggest a more practical possibility of using only estimated CSI pointing out to [32]. The simulation results provided indicate good error performance together with a relatively low complexity implementation.

In the context of Visible Light Communication (VLC) a modified OFDM scheme must be used, with the necessary constraint, that the optically transmitted signals must have nonnegative amplitudes. This gave rise to OFDM variants such as Asymmetrically Clipped OFDM (ACO-OFDM) [33] and Direct Current biased Optical OFDM (DCO-OFDM) [34]. Interference arises due to the clipping noise, and a pre-distortion is suggested and described in [35] to eliminate it. The novel pre-distorted scheme is then termed Pre-Distorted or PADO-OFDM.

The Inter-Cell Interference, as a major problem in cellular networks, attracted significant research interest in the past [36] as well as in recent years [37][38]. One approach is to coordinate transmissions between base stations of neighboring cells to perform one or a combination of the following techniques: Interference Alignment (IA) [38], or coordinated beamforming [39]. IA is in principle based on orthogonalization of the interfering signals: if we can, by some form of signal processing, force the interfering signal to be orthogonal to the useful transmission, then they actually do not interfere at all. As shown in [36, 38], this can be done to some extent, provided we sacrifice some of our signal space dimensions. In the simplest example by using only the real axis while the interfering transfer occupies only the imaginary axis of the IQ plane. In [40] Interference Alignment is discussed in detail for the context of K interfering users and it is shown, that the sum-spectral efficiency can be made to scale linearly with $K/2$, for which a modified transmission scheme termed the Interference-Free OFDM (IF-OFDM) is derived.

The coordinated beamforming is based in the ability of antenna array on the base station to direct the EM field in a narrow beam specifically pointed at the UE for which the data is heading. Then, if the neighboring cells are cooperating, such spatial beams may be optimized to minimize potential ICI. These mechanisms are often referred to as Inter-Cell Interference Coordination (ICIC) [41]. A complementary approach is to attempt to eliminate the ICI using no coordination, where the interference parameters are to be detected by the receiver alone. This is known as Blind Interference Parameter Detection (BIPD) [42][43] and usually comes with prohibitively complex receiver signal processing. A more recent approach is a Semi-BIPD based on utilization of received Demodulation-Reference Signals (DM-RS) sequence is described in [44].

When dealing with interference, an important research area deals with intentional OFDM disruption. This may be further divided into spoofing, sniffing and jamming, with the latter in focus of this survey. Jamming can be understood as intentional artificially created interference and there are many different techniques described in literature. Perhaps one of the simplest being the Narrow Band Jamming (NBJ), synonymous to Narrow Band Interference (NBI), or in some context denoted as Single-Tone Jamming/Interference. The principle is always the same: a narrow-band signal interfering with only a selected subset of the subcarriers. The Single-Tone Interference is analyzed in [45] both theoretically and by means of MATLAB simulation. Two scenarios are described: first with the jamming tone aligned with the target OFDM grid so that its frequency exactly matches one of the subcarriers, the second with a non-aligned interferer where the energy of the interfering signal flows over to several subcarriers. In [46] a somewhat similar scenario is presented with focus shifted to Chirp Spread Spectrum (CSS) system interfering with target OFDM transmission. The CSS modulation, used in the prominent IoT communication protocol LoRa, is based on time-variation of the signals frequency over a wide bandwidth. However, at each time instant, the CSS signal is a very narrowband waveform close to a single tone. [46] utilizes a special form of Fourier transform – the Fractional Fourier Transform (FRFT) as a tool necessary to properly analyze such CSS signal and then uses the resulting modified spectrum to derive an interference suppression algorithm. In [47] interference and jamming is analyzed in the context of Low-Earth Orbit (LEO) OFDM transmission: a variance-based Forward Consecutive Mean Excision (FCME) is utilized for detection of a narrowband interferer within the OFDM wideband channel and fast identification of the targeted subcarrier, while an overlapping windowed DFT frequency domain notch-based interference suppression is evaluated. In [48] an interefence cancellation technique based on neural networks is used for narrowband interference suppression. Another recent take on the NBJ problem (denoted somewhat differently as Spectral Concentrated Interference - SCI) is presented in [49], where a preliminary design of a combined OFDM-Spread Spectrum system is proposed.

[50] proposes a powerful jamming technique for disrupting OFDM, similar to the Repeat-Back Jamming technique [51], known for spread-spectrum systems. The proposed method disrupts the cyclic prefix of the OFDM symbols, which is essential for mitigating the interference caused by multipath fading. As long as the CP is longer than the maximum channel excess delay, the linear channel convolution can be converted to circular convolution for computationally feasible Frequency-Domain Equalization (FDE) described in section two. The key idea presented in [50] is to invalidate this condition by introducing a signal path with a delay exceeding the CP length. The jammer achieves this by capturing the transmitted OFDM signal and retransmitting it with a deliberate excessive delay. This creates a situation where the combined original and jamming signals mimic a multipath channel with an extended delay that exceeds the CP's length. Consequently, both IBI and consequent ICI cannot be fully suppressed by the receiver, disrupting the OFDM transmission. Since the jamming signal is simply a delayed version of the transmitted signal, the attack is difficult to detect. Unlike other jamming methods, this approach requires no synchronization with the OFDM transmission or knowledge of its detailed frame structure. On the other hand, it requires a powerful and ultra-fast signal processing on the jammer's side, since the FDE must first be performed and the transmitted block reconstructed by the jammer, sometimes in order of nanoseconds.

[52] then presents a potential mitigation technique based on attempting of a reconstruction of the transmitted OFDM symbol based on the decision feedback, where the one-tap FDE which is the heart of OFDM, is replaced by a more complex multi-tap FDE. This can reduce the error-floor otherwise introduced by the ICI that results as a consequence of exceeding CP length for the price of substantial increase of the receiver algorithm complexity. More recently [53] then presents an evolutional step in the form of Reduced Complexity Interference Cancellation (RCIC) with shorter detection delay, and reduced complexity with a compromise in resulting error performance.

Potentially the most effective class of jamming methods is the so called intelligent or smart jamming. Although these methods vary in details, they are based on the principle of understanding the organization of the OFDM resource grid as shown in (Fig.10), showing the allocation of data subcarriers along with pilot ones. What the structure indicates is that when it comes to intentional disruption, the subcarriers are not created equal: An OFDM receiver must estimate the channel frequency response $H(k)$ before it can perform the frequency-domain equalization as described by eq. (5). To enable this, OFDM systems transmit pilots, or reference symbols (RS), on pre-defined subcarriers alongside the data-carrying symbols. In 3GPP specifications, these reference symbols are generated at the PHY layer and referred to as the Cell-specific Reference signal (CRS). The CRS occupy approximately 14% of the resource elements and their exact positions and values are derived from the Cell ID [54]. Similarly, the synchronization signals represent only a small portion of the transmitted OFDM grid, and are therefore a potential target for jamming attack. [55] provides an analysis LTE transmission jamming based on the spoofing of the synchronization signals and gives simulational results confirming the effectivnes of this approach.

As described in [56], jamming of the pilot signals is a very effective way of disrupting OFDM transmission, provided the jammer can first identify the synchronization signals sent out by the base station in regular intervals. This method may be denoted as synchronous jamming, based on the fact that the jammer must synchronize to the network. As further shown in [54], perfect synchronization is not even necessary if the OFDM symbol duration is sufficiently long, and even an asynchronous disruption is feasible if the jammer transmits noise on all potential pilot subcarrier positions. Another highly effective disruption method is identified by [57] based on the knowledge of the 3GPP frame and superframe structure – the disruption of the Physical Broadcast Channel (PBCH) that caries the vital Master Information Block (MIB) header. Since the MIB provides the UE with important PHY-layer control parameters, a proposed intelligent jammer PBCH-IJ will target only the resource elements carrying the MIB to disrupt its decoding by the UE. As described in [57] this method represents a serious Denial of Service (DoS) attack.

4 OFDM Modifications and Candidates for 6G Modulation Scheme

Pre-standardization research activities are currently ongoing that aim at providing an answer to the question, what will the sixth generation (6G) of mobile communications be able to achieve and provide. The vision commonly held is that 6G will provide a technological platform enabling a unification of physical, digital and human worlds. It is expected to feature use of AI, machine learning, incorporation of integrated sensing and communication and more.

Already existing and new use cases will dictate requirements like extreme peak throughputs in orders of 100 Gbps, ultra-low latencies down to 0.1 ms not to mention the need for increased reliability, efficiency, security, etc... [58]. These requirements render existing modulation formats in their current form inadequate, prompting development of new modulation.

The choice of modulation format or waveform triggered discussions in earlier generations, with OFDM being used in both 4G and 5G. Depending on scenario OFDM is foreseen to be also used in 6G as no other waveform has shown substantial gain over OFDM not to mention the desire for efficient sharing of spectrum with the previous generation [59]. With that in mind is worth to mention few waveforms that are being considered as candidates for 6G networks.

Filtered OFDM (F-OFDM) is a variant of OFDM that introduces pulse shaping to reduce out-of-band emissions. It employs a filter on the subcarriers to reduce the side lobes, which helps to improve spectral efficiency and minimize interference with adjacent frequency bands [60].

Filter Bank MultiCarrier (FBMC) compared to OFDM, differs in three major ways. Firstly, it uses OQAM mapping instead of QAM mapping. With appropriate filtering this approach results in reduction of ICI. Secondly after IFFT process Poly Phase Network (PPN) filtering is applied, reducing ISI and ICI. Thirdly, no cyclic prefix is used because the best frequency and time localization through filtering and OQAM modulation process [61].

Universal Filtered Multi-Carrier (UFMC) can be seen as a generalization of F-OFDM and FBMC. In contrast to filtering entire band in F-OFDM and individual subcarriers filtering in FBMC, groups of subcarriers (sub-bands) are filtered in UFMC. Also, UFMC can still use QAM in contrast with FBMC, which enables usage of MIMO with this technology [62].

Discrete Fourier Transform-Spread-OFDM (DFTs-OFDM) is a variation of OFDM in which additional DFT step is added before OFDM modulation. It is similar to SC-FDMA. Main advantage is low PAPR (compared to OFDM) and simple equalization in the frequency domain [63].

Generalized Frequency Division Multiplexing (GFDM) is an alternative multicarrier technique that can solve the issues of using FBMC with MIMO and OFDM's long CP and usage of rectangular pulses. In GFDM, a nonorthogonal prototype filter is used to carry complex-valued symbols in time-frequency grid. To avoid IBI, a CP is added to each GFDM block. The ratio of CP length to the data block length can be smaller in GFDM compared to that in OFDM. As such, the bandwidth efficiency of GFDM can be higher than that of OFDM [61]. One method for improving the performance of GFDM to be used in networks of the future is to use it with another 6G technology Intelligent Reflecting Surfaces (IRS) [64].

Orthogonal Time Frequency Space (OTFS) waveform's main feature is that the information bearing signal is placed in the delay Doppler domain as opposed to the usual placement of similar signals in the time-frequency domain. This feature enables it to overcome several disadvantages of OFDM. OTFS is known to be more resilient to frequency offset and Doppler which is one of the key drawbacks of OFDM. OTFS can support higher mobility as well as higher frequency bands of operation. [65] It is fair to expect usage of a combination of OTFS and OFDM. For high Doppler shift scenarios, OTFS-based enhanced waveforms may be a good choice, while in indoor hotspot coverage scenarios, the advantages of OFDM multi-carrier-based enhanced waveforms can be utilized [66].

OFDM with Index Modulation (OFDM-IM) extends OFDM's signal constellations information by adding an additional level of modulation using the subcarrier index. In the OFDM-IM system model, the subcarriers are divided into two groups - active and inactive - based on a predetermined index pattern. Indices of the subcarriers are activated according to the information bits [67].

Index Modulation Non-Orthogonal Multiple Access (IM-NOMA) is a combination of multiple access technique index modulation and NOMA. IM-NOMA is designed to allow multiple users to share the same resources, by allocating different power levels and index values to the users. It is useful in scenarios where the channel conditions of different users are similar, as it allows more users to share the same resources and increases the capacity of the system [68].

Conclusion

In this paper we described the operation of an OFDM digital communications system chain operation (transmitter, channel and receiver) within the context of multipath fading channel. Various potential interference types are described in detail, and a survey of current interference mitigation techniques is provided with intentional interference - OFDM jamming included. A survey of potential OFDM modifications – candidates for the modulation scheme in the future 6G cellular networks is also provided.

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References

[1] "IEEE Draft Standard for Information Technology--Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks--Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: 320MHz Positioning," in IEEE P802.11bk/D3.0, July 2024 , vol., no., pp.1-112, 8 Oct. 2024.

[2] ETSI TS 136 201 V10.0.0 (2011-01) LTE; Evolved Universal Terrestrial Radio Access (E-UTRA);LTE physical layer;General description: (3GPP TS 36.201 version 10.0.0 Release 10)

[3] ETSI TS 138 201 V15.0.0 (2018-09) 5G; NR; Physical layer; General description (3GPP TS 38.201 version 15.0.0 Release 15)

[4] Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Physical Layer Specification CM-SP-PHYv3.1-I01-131029 Cable Television Laboratories, Inc. 2013

[5] M. Neinavaie and Z. M. Kassas, "Unveiling Starlink LEO Satellite OFDM-Like Signal Structure Enabling Precise Positioning," in IEEE Transactions on Aerospace and Electronic Systems, vol. 60, no. 2, pp. 2486-2489, April 2024, doi: 10.1109/TAES.2023.3265951.

[6] WI-FI ALLIANCE WPA3™ Specification, Version 3.4
[Available: https://www.wi-fi.org/system/files/WPA3%20Specification%20v3.4.pdf]

[7] The Beacon. What's new in Wi-Fi® security?
[Available online: https://www.wi-fi.org/beacon/the-beacon/whats-new-in-wi-fi-security]

[8] 5G SA: 5G-Standalone Summary. 2023.
[Available online: https://gsacom.com/paper/5g-market-snapshot-february-2023]

[9] G. Liu, Y. Huang, Z. Chen, L. Liu, Q. Wang and N. Li, "5G Deployment: Standalone vs. Non-Standalone from the Operator Perspective," in IEEE Communications Magazine, vol. 58, no. 11, pp. 83-89, November 2020, doi: 10.1109/MCOM.001.2000230

[10] Páleník, T.: Communication system design based on SDR platform: Exploiting the redundancy of an OFDM system, a dissertation. Sep. 2010, Slovak University of Technology Bratislava, Slovakia.

[11] Telesystem Innovations Inc., LTE in a Nutshell, White paper 2010.
[Online: https://frankrayal.com/wp-content/uploads/2017/02/LTE-in-a-Nutshell-Physical-Layer.pdf]

[12] Páleník, T., Farkaš, P.: Exploiting cyclic prefix redundancy in OFDM to improve performance of Tanner-graph based decoding. In Analog Integrated Circuits and Signal Processing an International Journal, ISSN 0925-1030, 2011, Vol. 69, pp. 143 – 152. DOI 10.1007/s10470-011-9662-1.

[13] Štefančík J.: Effect of synchronization errors on transmission error rate in OFDM systems, Diploma Thesis 2011 STU, Bratislava Slovakia

[14] A. Reza, F. Raisa and K. Abdullah, "Recent advances in interference mitigation using radio resource management in femtocell LTE/LTE — A networks," 2016 IEEE 3rd International Symposium on Telecommunication Technologies (ISTT), Kuala Lumpur, Malaysia, 2016, pp. 70-74, doi: 10.1109/ISTT.2016.7918087.

[15] A. Ibrahim, N. Seman and C. Y. B. Leow, "The investigation of MBMS over single frequency network in outdoor urban area," 2013 IEEE International RF and Microwave Conference (RFM), Penang, Malaysia, 2013, pp. 125-128, doi: 10.1109/RFM.2013.6757232.

[16] 3GPP TR 38.858 V18.1.0 (2024-03) Technical Specification Group Radio Access Network; Study on Evolution of NR Duplex Operation (Release 18), 3GPP, 2024.

[17] S. Wu, S. Zhang, Z. Xu and Z. Pan, "Flexible Resource Allocation Scheme for Non-Overlapping Subband Full Duplex Systems," 2023 International Conference on Wireless Communications and Signal Processing (WCSP), Hangzhou, China, 2023, pp. 1067-1072, doi: 10.1109/WCSP58612.2023.10404101.

[18] H. Tabata, H. Suganuma, and F. Maehara, “Impact of adjacent-channel interference on transmission performance in asynchronous FBMC/OFDM systems,” IEICE Commun. Express, vol. 10, no. 4, pp. 186–192, Apr. 2021.

[19] H. Yamada, H. Suganuma and F. Maehara, "System Capacity Analysis of Asynchronous FBMC and OFDM Systems in the Presence of Adjacent Channel Interference and Multipath Fading," 2022 IEEE Radio and Wireless Symposium (RWS), Las Vegas, NV, USA, 2022, pp. 171-173, doi: 10.1109/RWS53089.2022.9719951.

[20] Alaraimi A S, Hashimoto T. Performance analysis of polynomial cancellation coding for OFDM systems over time-varying Rayleigh fading channels[J]. IEICE transactions on communications, 2005, 88(2): 471-477.

[21] Alaraimi A S, Hashimoto T. Analysis of Coherent and Non-Coherent Symmetric Cancellation Coding for OFDM Over a Multipath Rayleigh Fading Channel[C]//IEEE Vehicular Technology Conference. IEEE, 2006: 1-5.

[22] Wang C L, Huang Y C. Intercarrier interference cancellation using general phase rotated conjugate transmission for OFDM systems[J]. IEEE Transactions on Communications, 2010, 58(3): 812-819

[23] X. Wu, Y. Xiao and L. Li, "Efficient Design of Intercarrier Interference Self-Cancellation for OFDM Systems," 2022 International Symposium on Networks, Computers and Communications (ISNCC), Shenzhen, China, 2022, pp. 1-5, doi: 10.1109/ISNCC55209.2022.9851808.

[24] S. Nagaraj and M. Sarkar, "Inter-Carrier Interference Reduction Technique for Backscattered OFDM," in IEEE Transactions on Vehicular Technology, vol. 73, no. 8, pp. 12237-12241, Aug. 2024, doi: 10.1109/TVT.2024.3381868.

[25] Y. Peng, Y. Zhang, S. He, L. Xiao, and T. Jiang, “Flexcatter: Low-power signal emulation for software-defined backscatter modulation,” in Proc. IEEE GLOBECOM, 2022, pp. 3983–3988.

[26] C. Huang, C. Wu and Y. Xiao, "An Intercarrier Interference Self-Cancellation Scheme for Space-Time/Frequency Line Coded OFDM," 2024 IEEE International Workshop on Radio Frequency and Antenna Technologies (iWRF&AT), Shenzhen, China, 2024, pp. 437-441, doi: 10.1109/iWRFAT61200.2024.10594108.

[27] C. Wu, Y. Xiao, Y. L. Guan, J. Wang, X. Li, and P. Yang, “Spacetime/frequency line coded OFDM: System design and practical implementation,” IEEE access, vol. 7, pp.151915–151928, 2019.

[28] Y. Zhao and S.-G. Haggman, “Intercarrier interference self-cancellation scheme for OFDM mobile communication systems,” IEEE Trans. Commun., vol. 49, no. 7, pp. 1185–1191, 2001.

[29] Z. Ou and H. Yang, "Expectation Propagation Based Signal Detection for MIMO-OFDM with Inter-Carrier Interference," 2023 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Beijing, China, 2023, pp. 1-6, doi: 10.1109/BMSB58369.2023.10211633.

[30] Y. Xiang, K. Xu, B. Xia, and X. Cheng, “Bayesian joint channel-and data estimation for quantized OFDM over doubly selective channels,”IEEE Trans. Wireless Commun., vol. 22, no. 3, pp. 1523-1536, Mar. 2023.

[31] T. P. Minka, “Expectation propagation for approximate Bayesian inference,” in Proc. 17th Conf. Uncertainty Artif. Intell. (UAI), 2001, pp. 362-369.

[32] W. L. Chin, “Nondata-aided Doppler frequency estimation for OFDM systems over doubly selective fading channels,” IEEE Trans. Commun., vol. 66, no. 9, pp. 4211-4221, Sept. 2018.

[33] J. Armstrong and B. J. C. Schmidt, “Comparison of asymmetrically clipped optical OFDM and DC-biased optical OFDM in AWGN,” IEEE Commun. Lett., vol. 12, no. 5, pp. 343–345, May 2008.

[34] J. Armstrong and A. J. Lowery, “Power efficient optical OFDM,” Electron.Lett., vol. 42, no. 6, pp. 370–372, Mar. 2006

[35] X. Huang, F. Yang, C. Pan and J. Song, "Pre-Distorted ADO-OFDM for Mutual Interference Eliminating with Low Complexity and Low Latency," 2020 IEEE International Conference on Communications Workshops (ICC Workshops), Dublin, Ireland, 2020, pp. 1-6, doi: 10.1109/ICCWorkshops49005.2020.9145474.

[36] V. R. Cadambe and S. A. Jafar, “Interference alignment and degrees of freedom of the k-user interference channel,” IEEE Transactions on Information Theory, vol. 54, no. 8, pp. 3425–3441, 2008.

[37] O. A. Antwi and A. Acakpovi, “Evaluation of inter-cell interference and ber on a downlink pdsch of the lte network,” in 2019 International Conference on Computing, Computational Modelling and Applications (ICCMA), 2019, pp. 96–965.

[38] S. Gollakota, S. D. Perli, D. Katabi. Interference alignment and cancellation. ACM SIGCOMM Computer Communication Review, 2009, Volume 39, Issue 4. Pages 159 - 170 https://doi.org/10.1145/1594977.1592588

[39] W. Shin, M. Vaezi, B. Lee, D. J. Love, J. Lee, and H. V. Poor, “Coordinated beamforming for multi-cell mimo-noma,” IEEE Communications Letters, vol. 21, no. 1, pp. 84–87, 2017.

[40] B. Lee, N. Lee, W. Shin and H. V. Poor, "Blind Interference Alignment With ISI: A New Look at OFDM for K -User Interference Channels," in IEEE Transactions on Signal Processing, vol. 68, pp. 4497-4512, 2020, doi: 10.1109/TSP.2020.3005310

[41] J. Moreira, E. R. da Silva, and P. R. Guardiero, “eICIC optimization improvements in downlink resource allocation in lte-a hetnets,” Journal of Communication and Information Systems, vol. 35, no. 1, pp. 15–24, 2020.

[42] B. Lee, N. Lee, W. Shin and H. V. Poor, "Blind Interference Alignment With ISI: A New Look at OFDM for K -User Interference Channels," in IEEE Transactions on Signal Processing, vol. 68, pp. 4497-4512, 2020, doi: 10.1109/TSP.2020.3005310

[43] J. Seo, J. Yang, H. W. Je, I. Kim and M. G. Kim, "Learning-based Blind Detection of Interference Parameters for NAICS System," ICC 2020 - 2020 IEEE International Conference on Communications (ICC), Dublin, Ireland, 2020, pp. 1-6, doi: 10.1109/ICC40277.2020.9148920.

[44] Y. Sun, J. Kang, W. Sui, S. Zhang, X. Chen and N. Dong, "Semi-Blind Multi-cell Interference Detection and Cancellation in 5G Uplink OFDM Systems," 2022 International Wireless Communications and Mobile Computing (IWCMC), Dubrovnik, Croatia, 2022, pp. 167-171, doi: 10.1109/IWCMC55113.2022.9824834.

[45] N. Jian-jian, L. Wen-sheng, B. Bin and X. Bohao, "Research on the Method of Using Single-tone Interference to Jam OFDM Signal," 2019 IEEE 2nd International Conference on Electronic Information and Communication Technology (ICEICT), Harbin, China, 2019, pp. 448-452, doi: 10.1109/ICEICT.2019.8846366.

[46] C. Zhang, J. Shi, Z. Zhang, Y. Liu and X. Hu, "FRFT-Based Interference Suppression for OFDM Systems in IoT Environment," in IEEE Communications Letters, vol. 23, no. 11, pp. 2068-2072, Nov. 2019, doi: 10.1109/LCOMM.2019.2939236.

[47] W. Wang, Y. Huang, Z. Wu, Y. Liu and H. Han, "Research on Variance-Based FCME Anti-Jaming Algorithm in Spaceborne OFDM System," 2022 14th International Conference on Signal Processing Systems (ICSPS), Jiangsu, China, 2022, pp. 651-656, doi: 10.1109/ICSPS58776.2022.00120.

[48] X. Wang, Y. Hou and X. Shen, "Narrowband Interference Cancellation Technology of OFDM System based on Artificial Neural Network," 2020 IEEE 3rd International Conference on Electronics Technology (ICET), Chengdu, China, 2020, pp. 675-678, doi: 10.1109/ICET49382.2020.9119503

[49] K. Vanin, H. -G. Ryu, A. R. Safin and O. V. Kravchenko, "Interference-Robust OFDM Communication System using Weight Functions," 2023 International Conference on Artificial Intelligence in Information and Communication (ICAIIC), Bali, Indonesia, 2023, pp. 154-157, doi: 10.1109/ICAIIC57133.2023.10067021.

[50] L. Li, S. Tian, J. Huang, P. Zhang, "Efficient and unrecognizable OFDM jamming by failing the cyclic prefix functionality," 2017 9th International Conference on Wireless Communications and Signal Processing (WCSP), Nanjing, China, 2017, pp. 1-6, doi: 10.1109/WCSP.2017.8170905.

[51] R. S. Orr, "Performance of MFSK in Simultaneous Partial-Band and Repeat-Back Jamming," MILCOM 1982 - IEEE Military Communications Conference - Progress in Spread Spectrum Communications, Boston, MA, USA, 1982, pp. 28.5-1-28.5-4, doi: 10.1109/MILCOM.1982.4805968.

[52] A. F. Molisch, M. Toeltsch, and S. Vermani, “Iterative methods for cancellation of intercarrier interference in OFDM systems,” IEEE Trans. Veh. Technol., vol. 56, no. 4, pp. 2158-2167, Jul. 2007

[53] W. Shi, C. Zhao and M. Jiang, "Reduced Complexity Interference Cancellation for OFDM Systems With Insufficient Cyclic Prefix," 2019 11th International Conference on Wireless Communications and Signal Processing (WCSP), Xi'an, China, 2019, pp. 1-6, doi: 10.1109/WCSP.2019.8928022.

[54] M. Lichtman, R. P. Jover, M. Labib, R. Rao, V. Marojevic and J. H. Reed, "LTE/LTE-A jamming, spoofing, and sniffing: threat assessment and mitigation," in IEEE Communications Magazine, vol. 54, no. 4, pp. 54-61, April 2016, doi: 10.1109/MCOM.2016.7452266.

[55] X. Li, Xue Xie, Juan Zeng and Y. Wang, "Vulnerability analysis and verification for LTE initial synchronization mechanism," 2015 36th IEEE Sarnoff Symposium, Newark, NJ, USA, 2015, pp. 150-154, doi: 10.1109/SARNOF.2015.7324660.

[56] T. C. Clancy, "Efficient OFDM Denial: Pilot Jamming and Pilot Nulling," 2011 IEEE International Conference on Communications (ICC), Kyoto, Japan, 2011, pp. 1-5, doi: 10.1109/icc.2011.5962467.

[57] S. D. Wang, H. -M. Wang, W. Wang and V. C. M. Leung, "Detecting Intelligent Jamming on Physical Broadcast Channel in 5G NR," in IEEE Communications Letters, vol. 27, no. 5, pp. 1292-1296, May 2023, doi: 10.1109/LCOMM.2023.3260194.

[58] H. Tataria, M. Shafi, A. F. Molisch, M. Dohler, H. Sjöland and F. Tufvesson, "6G Wireless Systems: Vision, Requirements, Challenges, Insights, and Opportunities," in Proceedings of the IEEE, vol. 109, no. 7, pp. 1166-1199, July 2021, doi: 10.1109/JPROC.2021.3061701.

[59] S. Parkvall, H. Wiemann, “6G RAN – key building blocks for new 6G radio access networks,” Ericsson’s Blog post, May 2024, Available: https://www.ericsson.com/en/blog/2024/5/future-6g-radio-access-network-design-choices

[60] F. A. P. de Figueiredo, N. F. T. Aniceto, J. Seki, I. Moerman and G. Fraidenraich, "Comparing f-OFDM and OFDM Performance for MIMO Systems Considering a 5G Scenario," 2019 IEEE 2nd 5G World Forum (5GWF), Dresden, Germany, 2019, pp. 532-535, doi: 10.1109/5GWF.2019.8911702.

[61] B. Khan and F. J. Velez, "Multicarrier Waveform Candidates for Beyond 5G," 2020 12th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP), Porto, Portugal, 2020, pp. 1-6, doi: 10.1109/CSNDSP49049.2020.9249568.

[62] Taher, Montadar. (2019). Enhanced 5G Throughput using UFMC Multiplexing. Journal of Southwest Jiaotong University. 54. 10.35741/issn.0258-2724.54.5.25.

[63] R. Bomfin, A. Nimr and G. Fettweis, "A Study on Iterative Equalization for DFTs-OFDM Waveform under sub-THz Channels," 2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 2022, pp. 1-6, doi: 10.1109/CCNC49033.2022.9700594.

[64] S. M. J. A. Tabatabaee, M. Towliat, M. Rajabzadeh and F. S. Khodadad, "Intelligent-Reflecting-Surface-Assisted GFDM Communication Systems," in IEEE Systems Journal, vol. 17, no. 2, pp. 2858-2867, June 2023, doi: 10.1109/JSYST.2023.3237594.

[65] Suvra Sekhar Das; Ramjee Prasad, "OTFS: Orthogonal Time Frequency Space Modulation A Waveform for 6G," in OTFS: Orthogonal Time Frequency Space Modulation A Waveform for 6G , River Publishers, 2021, pp.i-xxvi.

[66] B. Li et al., "Research on OTFS Systems for 6G," 2022 IEEE International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom), Wuhan, China, 2022, pp. 1498-1503, doi: 10.1109/TrustCom56396.2022.00213.

[67] Y. Lian, X. Bi, P. Zhao and Y. Jiang, "A Research on Modulation and Detection in OFDM-IM System," 2023 3rd Asia-Pacific Conference on Communications Technology and Computer Science (ACCTCS), Shenyang, China, 2023, pp. 27-33, doi: 10.1109/ACCTCS58815.2023.00008.

[68] P. Lavanya and G. S. Sankar Varma, "IM-NOMA: A Hybrid OFDM-IM and OFDM Systems for Enhancing Achievable Rate and SNR with QPSK," 2024 Third International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT), Trichirappalli, India, 2024, pp. 1-5, doi: 10.1109/ICEEICT61591.2024.10718520.

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ARTIFICIAL INTELLIGENCE IN MEDICINE AND PROJECT: EARLY WARNING OF ALZHEIMER'S DISEASE

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Abstract:

In the last decade, artificial intelligence and machine learning have made a significant impact on the healthcare industry, particularly in the areas of clinical decision support and image analysis. We provide an overview of publications and applications of artificial intelligence in medicine, highlighting key use cases. Artificial intelligence can extract insights from vast, seemingly unrelated data, including medical records. IBM Watson Oncology has played a key role in lung cancer treatment decisions. Artificial intelligence tools are improving diagnosis and treatment predictions, thereby improving healthcare delivery. Clinical decision support tools provide quick access to relevant patient information, while in the field of medical imaging, they help detect findings that radiologists might miss. Artificial intelligence has become an integral part of modern healthcare, used in both clinical settings and medical research. This article explores current trends in the applications of artificial intelligence for early prediction of cardiovascular and neurodegenerative diseases. We present our results that improve disease prediction in neurodegenerative diseases. The integration of artificial intelligence into medicine is becoming increasingly efficient and accurate, but raises ethical concerns such as ensuring patient privacy and maintaining human oversight.

Keywords:

*Artificial intelligence, machine learning, prediction of diseases,
prediction of neurodegenerative diseases.*

Introduction

Artificial Intelligence (AI) has revolutionized various industries, and medicine is no exception. The integration of AI into healthcare promises a future of better patient outcomes and greater operational efficiencies, from increasing diagnostic accuracy to personalizing treatment plans.

AI algorithms make it possible to identify and diagnose a spectrum of diseases by analysing medical images such as ultrasound, X-rays, CT and MRI scans, and X-ray absorptiometry. Artificial intelligence, artificial neural network and logistic regression methodologies have been successfully used to diagnose complex medical conditions. Of note are tuberculosis, hypertension, stroke, cancer, Alzheimer's disease, liver disease, skin diseases, diabetic retinopathy, and chronic diseases [1].

In the 2000s, AI has progressed from machine learning to deep learning, which is characterized by the development of convolutional neural networks (CNN). These networks can generate results and classify medical knowledge, bypassing the need for manual input and expertise [2]. Currently, CNNs are in high demand in image processing, which resemble the neurons of the human brain. They are highly accurate, similar to human expertise [3] and can use spatial recognition techniques to evaluate different imaging modalities to aid in diagnosis [4].

The combination of AI with conventional medical imaging techniques has accelerated the diagnosis of diseases. For example, analysis of retinal images with the help of AI helps in early detection of diabetic retinopathy [5]. In addition, natural language processing (NLP) enables rapid analysis of textual clinical records and offers insights for accurate diagnosis and patient care [6]. In radiology, AI algorithms have demonstrated proficiency in interpreting medical images and assist radiologists in detecting various diseases. AI-powered systems can detect anomalies in X-ray, MRI, and CT scans, leading to faster and more accurate diagnosis of diseases [7], [8].

1 Top Examples of AI Applications in Medicine

In this section, we explore the significant advances and applications of AI in medicine, highlighting key examples and their implications for use. IBM was a major milestone with Watson Health in the healthcare. IBM Watson Oncology, which was originally launched in 2013 to provide lung cancer treatment options, was sold by IBM in 2022, now a Merative program. Artificial intelligence has also made significant advances in radiology and cardiology, improving workflows and diagnostic accuracy.

1.1 IBM Watson Health and Merative Artificial Intelligence Milestone

IBM Corp. has been building a program for the health care industry for years. In 2013, IBM launched a lung cancer treatment option at a cancer center in New York City using IBM Watson Oncology, although the program did not meet the expectations of the financially challenged program, IBM nonetheless promoted the program for several years and tested the system at several hospitals (Strickland, 2019). In 2016, IBM purchased Truven Health and renamed the program Watson Health, making the entire system more comprehensive. The system included analytics tools, benchmarks, research, and services for the healthcare industry, including hospitals, health plans, physicians, biotech companies, and medical device companies. In 2022, IBM sold the system to Francisco Partners for $1 billion, which included Micromedex clinical support, providing healthcare providers with timely and reliable information to support clinical decision-making [9].

Merative provides tools for clinical decision support, data management, and analytics:

- **Clinical Decision Support**: Helps healthcare professionals make informed decisions with access to comprehensive drug databases and medical resources.
- **Data Management**: Facilitates efficient clinical trials and data collection through platforms like Zelta, which supports electronic data capture (EDC) and other trial management tools.
- **Imaging Solutions**: Offers advanced imaging tools and workflows to enhance radiology and cardiovascular services.

The Merative supports clinical trials through its **Zelta platform**, which offers a comprehensive suite of tools designed to streamline and enhance the clinical trial process:

- Electronic Data Capture facilitates efficient data collection and management, ensuring accuracy and compliance.
- Clinical Trial Management System provides tools for planning, tracking, and managing clinical trial activities.
- Electronic Trial Master File organizes and stores essential documents electronically, improving accessibility and regulatory compliance.

- Electronic Clinical Outcome Assessment enables participants to report outcomes electronically, enhancing data quality and participant engagement.
- Electronic Consent simplifies the consent process by allowing participants to review and sign consent forms electronically.

Artificial intelligence has significantly impacted radiology and cardiology by streamlining workflows and improving diagnostic accuracy. In radiology, solutions like Merge PACS facilitate efficient image management. In cardiology, data management workflows within cardiovascular services have been highly rated, with Merge Cardio and Merge Hemo solutions being highly rated in 2024 by US authorities.

1.2 The Medical Imaging Revolution

Enlitic's Curie program normalizes and extracts valuable information from medical images, addressing inefficiencies and data fragmentation in radiology. Similarly, Viz.ai has made advances in real-time analysis of medical imaging data, including CT, MR, ECG and echocardiography. The Viz.ai program has been approved by the FDA for accelerating diagnosis and treatment by providing real-time insights and automating evaluations [10].

Key features **Enlitic app** include:

- **Data Standardization**: Reduces variability in labeling and improves data quality, enhancing workflow efficiency.
- **Data Protection**: Uses AI to deidentify or anonymize patient data while maintaining clinical relevance.
-

Viz.ai focuses on real-time analysis of medical imaging data, including CT, MR, ECG, and echocardiography. It has been approved by the FDA for its ability to accelerate diagnosis and treatment by providing real-time insights and automating evaluations

Key features **Viz.ai** include:

- **Advanced Algorithms**: Analyzes medical imaging to provide real-time reports and automated assessments, speeding up diagnosis and treatment.
- **FDA Approval**: Viz.ai is the first computer-assisted triage and alerting platform to receive De Novo clearance from the FDA.

(Fig.1) is an example of using Viz.ai. In this case, a patient with sudden chest pain was quickly diagnosed with acute type B dissection using the Viz.ai artificial intelligence system. The Viz.ai system analyzed the CT and MR images in real time and provided immediate insights that led to a rapid diagnosis. The system immediately notified a specialist doctor to confirm the diagnosis. (Fig.1) shows the communication between Viz.ai and the specialist doctor directly online on the mobile viewing the MRI and CT images to validate the diagnosis made by artificial intelligence.

Fig.1. Example of Viz and physician program communication, adapted from [10][1].

1.3 Improving Electronic Health Records

Adoption of Electronic Health Records (EHRs) in the U.S. has significantly increased, with 96% of non-government hospitals now digitally documenting patient information. This widespread adoption has improved the efficiency and accuracy of patient data management.

Application Regard

Regard is an AI-driven tool that rapidly digitizes patient information by analyzing EHR data and transforming it into actionable insights. It helps in suggesting diagnoses and generating care plans, thereby closing the clinical insights gap.

Regard improves patient care by addressing the Clinical Insights Gap, which is the challenge of utilizing the vast amounts of patient data available in Electronic Health Records (EHRs). Here are keyways Regard enhances patient care:

- Analyzes all available patient data, including years of medical history, to uncover hidden insights that might be missed during routine reviews.
- Comprehensive analysis helps in identifying undiagnosed conditions, potential medication interactions, and other critical health issues.
- The platform provides clinicians with actionable insights by suggesting diagnoses and generating care plans based on the analyzed data.
- This allows healthcare providers to make more informed, data-driven decisions, improving the accuracy and quality of patient care.

[1] https//:www.viz.ai, the proven AI-powered care coordination platform

Application DeepScribe

DeepScribe uses artificial intelligence to transcribe and analyze patient interviews in real time. This ensures comprehensive and accurate documentation, allowing physicians to focus more on patient interaction rather than note-taking [10].

In a clinical setting, DeepScribe was implemented to assist physicians during patient visits. The AI platform recorded and transcribed conversations, enabling physicians to concentrate on interacting with patients. This led to increased accuracy of medical records and improved the overall patient experience.

1.4 Radiation Planning for Cancerous Diseases

Artificial intelligence is increasingly being integrated into brain tumor radiation treatment planning to improve accuracy and efficiency. AI algorithms can analyse medical imaging data, such as MRI and CT scans, to identify tumour boundaries and critical structures in the brain with high accuracy. This capability allows them to optimise radiation dose distribution, minimising exposure to healthy tissue while maximising the impact on tumours. In addition, machine learning models can predict patients' responses to radiotherapy, which aids in personalized treatment planning.

Recent publications in the field of artificial intelligence in radiation oncology include studies exploring the use of deep learning algorithms to segment tumors and optimize treatment planning. For example, a recent paper discusses the use of convolutional neural networks (CNNs) to automatically detect brain tumors from magnetic resonance images. An additional 274 contours obtained by processing CT scans were included in the analysis. The highest DSC values were obtained for the brain (DSC 1.00), left and right eyeballs, and mandible (DSC 0.98). The structures with greater MC adjustment were optic nerves, and the cochlea.

Recent advances in artificial intelligence for radiotherapy include the development of sophisticated algorithms that improve tumor segmentation and treatment planning. Deep learning techniques are now being used to analyze complex image data, leading to more accurate delineation of tumors and surrounding tissues [11]. AI-based tools can also automate the treatment planning process, significantly reducing the time required to create a plan. In addition, by analysing vast amounts of data, artificial intelligence can help predict treatment outcomes and tailor treatment to individual patient needs. This AI integration is expected to reduce treatment time, minimize side effects and ultimately improve the overall survival rate of patients undergoing radiotherapy. The goal of using AI in this context is to improve clinical outcomes and reduce side effects associated with traditional methods of radiotherapy.

1.5 Health Care Applications

Artificial intelligence is key in screening for early prediction of diseases such as heart disease and neurodegenerative diseases. Predictive and comparative data helps design options for comprehensive care plans. For example, blood pressure monitoring is one of the priorities of the Anura mobile app [12]. Transdermal optical imaging is based on state-of-the-art techniques to extract the blood pressure signal from video. It first tracks 17 unique regions of interest on the face in red, green and blue color channels to produce multiple raw signals. In general, using multiple regions yields a more robust and reliable signal. Such a feature provides rich information about the state of the neurovascular system. Unlike other video-based technologies, transdermal optical imaging divides each video image into multiple layers called bit planes within the RGB color channel. A computational model, which was previously trained using continuous blood pressure monitoring, allows the hemoglobin-rich RGB signals to be tracked. This technique significantly improves the signal-to-noise ratio and protects the signals from being affected by factors such as skin tone and variable lighting conditions. After extracting the raw blood flow signal from the video recording, digital signal processing techniques are used to estimate the plethysmograph signal (Fig.2). Such techniques include digital filters (e.g. high pass, low pass, band pass). Finally, machine learning algorithms then extract the information to model and detect the desired parameters.

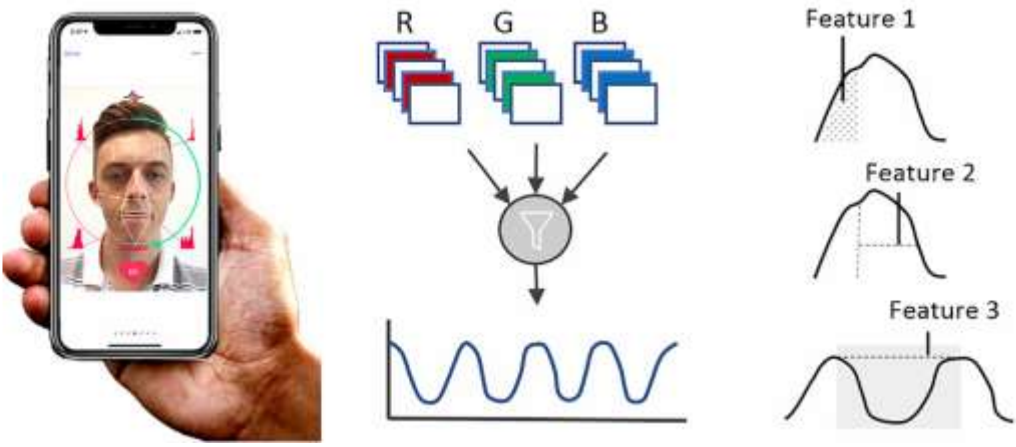

Fig.2. Schematic of blood pressure prediction using transdermal optical imaging.

Anura uses a mobile app to track the patient's face, using light and skin translucency to capture changes in blood flow using a conventional video camera over a 30-second period. The Anura app is available on iOS and Android devices for personal use. Anura is the first non-contact blood pressure app that also measures heart rate, stress level, BMI and cardiovascular disease risk with medical accuracy.

2 Project Early Warning of Alzheimer's Disease

The most common neurodegenerative diseases are Alzheimer's disease (AD), Parkinson's disease (PD) and others, which are often determined by neurological and psychiatric examination using a variety of ancillary tests such as magnetic resonance imaging, positron emission tomography (PET), speech and vision tests, or laboratory tests of cerebrospinal fluid or blood. In this article, we focus on two neurodegenerative diseases in particular: AD, including the mild cognitive impairment (MCI) stage, and PD.

The number of patients with neurodegenerative diseases in the world is increasing every year, similarly in Slovakia, according to the National Centre of Health Information there are more than 25 thousand patients in Slovakia and according to the latest surveys up to twice as many. The goal of our research and the Early Warning of Alzheimer's (EWA) project was to develop a methodology for collecting data from patients and healthy people. An important component besides the mobile application was to process the participants' speech data using NLP, i.e. tokenization, stemming, syntactic analysis, non-linear naming and sentiment analysis to use artificial intelligence for early diagnosis of Alzheimer's disease, MCI and PD. As part of the EWA project, we analysed the current state of research until 2021 [13].

In the analysis of spontaneous speech, prosody is most often studied in people with neurodegenerative diseases because it relates to the phonetic and phonological properties of speech. Specifically, it involves the analysis of speech rhythm along with other parameters related to temporal and acoustic measures of voice, such as articulatory rhythm, vocal intensity (analysis of loudness and changes in amplitude over time), timing and frequency (changes in acoustic signal frequencies, color or shape structure). There are studies that jointly evaluate the process of extracting features from the vocal signal using different vocal parameters and different qualifiers.

Table 1. Data distribution over neurodegenerative disorder.

Condition	Total number of samples	Filtered number of samples
No neurodegenerative disorder	1273 (~80%)	1011 (~80%)
Mild Cognitive Impairment (MCI)	70 (~4.4%)	59 (~4.6%)
Alzheimer’s disease (AD)	56 (~3.5%)	47 (~3.7%)
Parkinson’s disease (PD)	154 (~9.7%)	154 (~12.1%)
Other neurodegenerative disorder	41 (~2.6%)	-

We designed a mobile app for people who responded with speech to 2 types of images - one-word small images and descriptive large images. While the small pictures depicted a single object or activity, the large pictures consisted of scenes that required more attention to detail. The dataset collected from people using the app consisted of more than 1500 recorded samples from healthy and sick people (Tab.1). The data consisted of data sources: basic information about the patient such as age, gender, education, statistical data about the speech recordings (number of spaces, length of spaces between words, number of words used, phonetics), etc. We extracted these symptoms from people's voice recordings describing the images they saw on a smartphone or tablet. The audio recordings were processed using specialized software and a suitable feature selection algorithm for speech and sound processing, which was developed at the Institute of Computer Science, Slovak Academy of Sciences in Bratislava. The experiments showed that recordings of patients' spontaneous speech in Slovak while describing images using a mobile app can also reveal subtle changes in the voice of people with neurodegenerative diseases, which helped in early detection of Alzheimer's disease and PD. As a result, we obtained more than 60,000 different symptoms from each participant. We analyzed this data as well as with the audio recordings in more detail in a study [14].

Machine learning (ML) and Deep Learning (DL) techniques are used for several of the above methods of detecting neurodegenerative disease. The most used methods for machine learning are support vector machines, decision trees, k-nearest neighbours, linear regression, linear discriminant analysis, neural networks, Bayesian networks and techniques by combining models such as bootstrap aggregating, boosting, stacking detailed [15]. To evaluate machine learning models, accuracy is most often used according to the relationship. Test accuracy and sensitivity are two important parameters used to evaluate diagnostic tests:

Accuracy = (TP + TN) / (TP + TN + FP + FN),
Sensitivity = TP / (TP + FN),
Specificity = TN / (TN + FP),
where the values are TP - true positive, TN - true negative,
FP - false positive and FN - false negative classifications.

Accuracy reflects the overall ability of the test to correctly identify individuals, whether they are sick or healthy. It indicates the percentage of all correct results (both positive and negative) from all tests performed. **Sensitivity** reflects the ability of the test to correctly identify individuals with the disease. **Specificity** measures the ability of a test to correctly identify individuals who do not have the disease.

The process of obtaining the data needed to best predict AD and PD according to the proposed procedure in patients diagnosed with AD, MCI and PD consisted of recording how they responded to the displayed images with spontaneous speech, which we recorded in a database. In the case of diagnosed patients, we used all available information from their medical history to establish an accurate diagnosis. We recorded three selected psychological tests, of which the Montreal Cognitive Test proved to be the most important.

We evaluated the data obtained from patients with Alzheimer's and Parkinson's disease and from a group of healthy people using special artificial intelligence algorithms in order to best determine accuracy, sensitivity and specificity. (Tab.1) shows the summary counts of subjects compared to subjects after filtering the data prepared for the machine learning algorithms. As can be seen from the table, there is only a small proportion of positive diseased samples compared to samples without neurodegenerative disease, so for the algorithms we had to fit the data to the same distribution for all groups.

One way to deal with the imbalance of the dataset is to create more samples from the minority class to approximately even out the distribution of the dataset or, conversely, to reduce the majority healthy group. We used four methods: random resampling (Random), synthetic minority oversampling technique (SMOTE), adaptive synthetic algorithm (ADASYN), and TomekLinks. Of the 10 machine learning algorithms, two were clearly the best: Linear regression and Light gradient-boosting machine regression (LGBM regression). (Tab.2) shows the results of the two best algorithms with found accuracy, specificity and sensitivity for Alzheimer's disease. This table shows very good results for early prediction of AD [16].

Table 2. Comparative analysis results of the best two algorithms with sampling for AD.

Machine Learning Algorithm	**Sampling Method**	**Avg. Accuracy [%]**	**Avg. Sensitivity [%]**	**Avg. Specificity [%]**
Linear Regression	TomekLinks	96.6	74.52	98.91
Linear Regression	Random	96.33	74.52	98.61
Linear Regression	SMOTE	95.97	72.64	98.41
Linear Regression	ADASYN	95.88	75.47	98.02
LGBM Regression	SMOTE	95.97	68.86	98.81
LGBM Regression	Random	95.08	70.75	97.61
LGBM Regression	TomekLinks	94.81	69.81	97.43
LGBM Regression	ADASYN	93.91	80.17	95.35

According to (Tab.2), we selected the linear regression algorithm with TomekLinks sampling to predict Alzheimer's disease, where the accuracy of correctly identifying sick or healthy people was remarkably high 96.6% with a bias of 1.9%, while the sensitivity of correctly identifying people with Alzheimer's disease was sufficient 74.5%. The specificity was 98.6%, which means that the rate of correct identification of a healthy person was very high.

As part of a research collaboration with the Memory Centre in Bratislava, we applied artificial intelligence to analyze speech patterns for early detection of Alzheimer's disease according to the above procedure. This innovative approach has enabled early diagnosis and intervention, improving care for patients in the early stages of the disease. At the same time, health insurers are currently preparing clinical testing of our EWA project application for screening the population of the Bratislava region in people aged 50 years and older.

3 Discussion

Clear and explainable AI algorithms are crucial for building trust and making better clinical decisions. The debate on AI risks in healthcare underscores the importance of data protection and seamless integration into existing systems, highlighting the need for enhanced interoperability. Ethical concerns about AI in medical decisions emphasize the necessity of transparency and explainability, along with establishing ethical guidelines to ensure interpretable diagnoses.

To harness AI advancements, countries are developing governance frameworks, including legislation. The FDA has issued a discussion paper on regulatory frameworks for AI and machine learning-enabled software and medical devices.

To leverage advances in AI, countries are developing governance frameworks, including legislation. The FDA has issued a discussion paper on regulatory frameworks for software and medical devices using AI and machine learning.

AI-based diagnostic procedures offer speed, accuracy, cost-effectiveness and the ability to process large amounts of medical data. Research in Nature Medicine showed that AI models for breast cancer diagnosis outperformed traditional methods with increased training data. Implementing AI into medical imaging has also reduced costs by reducing reliance on expensive tests.

The increasing use of AI for disease diagnosis raises ethical issues, particularly the transparency and explainability of algorithms. AI has great potential to improve diagnostic accuracy, patient outcomes, and healthcare efficiency if the challenges and ethical considerations are properly addressed.

Clear and understandable AI algorithms are key to building trust and making better clinical decisions. The discussion on the risks associated with AI in healthcare highlights the importance of data protection and seamless integration into existing systems, emphasizing the need for increased interoperability.

Ethical concerns about AI in medical decisions highlight the need for transparency and explanation, along with the establishment of ethical guidelines to ensure interpretable diagnoses.

AI algorithms can be biased because of training data, leading to skewed results, as has been shown in studies on racial bias. Strict privacy measures such as encryption and data anonymization are essential for patient confidentiality and compliance with regulations such as GDPR and HIPAA. Patient consent is also key when using AI in diagnostics.

The integration of AI into healthcare brings challenges, particularly in the areas of privacy and security. Healthcare facilities need to ensure anonymization and protection of patient data. Interoperability is another challenge as it requires consistent data exchange between AI systems and existing infrastructure.

Conclusion

The implications of AI in medicine are both promising and transformative. The ability to process vast amounts of data, uncover patterns, and provide insights will lead to more accurate diagnoses and personalized treatments. This will empower healthcare professionals by offering data-driven recommendations, improving decision-making and reducing error rates. However, this integration raises ethical and regulatory concerns, such as ensuring patient privacy and maintaining human oversight. Healthcare workers will need to adapt to the role of AI and acquire the skills to work effectively with intelligent systems.

The integration of artificial intelligence into medicine is transforming healthcare delivery, making it more efficient, accurate and personalized. As AI continues to evolve, its applications in medicine will expand and offer new opportunities for patient care and medical research. The future of healthcare lies in the seamless integration of AI technologies, promising a new era of medical advancements and better patient care.

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References

[1] Kumar, Y, Koul, A, Singla, R, et al. (2023). Artificial intelligence in disease diagnosis: a systematic literature review, synthesizing framework, and future research agenda. J Ambient Intell Humaniz Comput 2023;14:8459-8486.

[2] Bhatt, C, Kumar, I, Vijayakumar, V, et al. (2021). The state of the art of deep learning models in medical science and their challenges. Multimed Syst 2021;27:599-613.

[3] Barragán-Montero A, Javaid U, Valdés G, et al. (2021). Artificial intelligence and machine learning for medical imaging: a technology review. Phys Med 2021;83:242-256.

[4] Xie, S, Yu, Z, Lv, Z. (2021). Multi-disease prediction based on deep learning: a survey. Comput Model Eng Sci 2021;128:489-522.

[5] Gulshan, V, Peng, L, Coram, M, et al. (2016). Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. JAMA 2016; 316:2402-2410.

[6] Miotto, R, Li, L, Kidd, B, et al. (2016). Deep patient: an unsupervised representation to predict the future of patients from the electronic health records. Sci Rep 2016;6:26094; Published 2016.

[7] Esteva, A, Kuprel B, Novoa RA, et al. (2017). Dermatologist-level classification of skin cancer with deep neural networks. Nature 2017;542:115-118.

[8] Hosny, A, Parmar C, Quackenbush J, et al. (2018). Artificial intelligence in radiology. Nat Rev Cancer 2018;18:500-510.

[9] Chesbrough, H. (2024). Open Innovation: Accomplishments and Prospects for the Next 20 Years. California Management Review, 67(1), 164-180. https://doi.org/10.1177/00081256241273964

[10] McFarland, A. (2024). AI in Healthcare: Top 5 Medical AI Tools We Use in 2024. Techopedia. Retrieved from www.techopedia.com/ai-in-healthcare-top-medical-ai-tools

[11] Wang, T., Hsu, M., Lee, W., Pan, H., Yang, H., Lee, C., & Wu, Y. (2024). Brain metastasis tumor segmentation and detection using deep learning algorithms: A systematic review and meta-analysis. Radiotherapy and Oncology, 190, 110007. htps://doi.org/10.1016/j.radonc.2023.110007

[12] Barszczyk, A., Lee, K. (2019). Measuring Blood Pressure: from Cuff to Smartphone. *Curr Hypertens Rep* 21, 84 (2019). https://doi.org/10.1007/s11906-019-0990-3

[13] Ružický, E., Kozák, Š., Lacko, J., Štefanovič, J., Zimmermann, A., Rusko, M., Brandoburová, P., & Škorvánek, M. (2021). Comparison and analysis of the use of advanced methods of artificial intelligence for neurodegenerative diseases. *International Journal of Information Technology Applications, 10*(1), 35-46.

[14] Rusko, M., Sabo, R., Trnka, M., Zimmermann, A., Malaschitz, R., Ružický, E., Brandoburová, P., Kevická, V., & Škorvánek, M. (2024). Slovak database of speech affected by neurodegenerative diseases. *Scientific Data, 11,* Article 171. https://doi.org/10.1038/s41597-024-04171-6

[15] Raschka, S., Liu, Y. (H.), & Mirjalili, V. (2022). Machine Learning with PyTorch and Scikit-Learn: Develop Machine Learning and Deep Learning Models with Python. 2nd ed. Birmingham: Packt Publishing. ISBN 978-1801819312.

[16] Képešiová, Z, Ružický E, Kozák Š, Zimmermann, A., Malaschitz, R. (2023). Application of Advanced Machine Learning Algorithms for Early Detection of Mild Cognitive Impairment and Alzheimer's Disease. IEEE 2023, Conference Bulgaria.

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