ARTIFICIAL INTELLIGENCE & VIRTUAL REALITY 2023
1st INTERNATIONAL WORKSHOP
June 27, 2023, Bratislava, Slovakia

PROCEEDINGS

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Proceedings

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Preface

The International Workshop

ARTIFICIAL INTELLIGENCE & VIRTUAL REALITY (AI & VR), June 27-28, 2023

is organized by the SLOVAK SOCIETY FOR CYBERNETICS AND INFORMATICS (SSKI) under the auspices of the
FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY, SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA
and the
FACULTY OF INFORMATICS, PAN-EUROPEAN UNIVERSITY IN BRATISLAVA.

The aim of the workshop is to bring together original research articles and review articles highlighting research on implementing artificial intelligence in augmented and virtual reality systems as well as to provide a general forum for researchers, university teachers and users dealing with practical problems of AI &VR.

Contributions included in the workshop program are from the following fields:
• 		Virtual reality platforms
• 		AI platforms for VR/AR and Vision for VR/AR
• 		Machine learning and signal processing for multimodal interaction
• 		Human-virtual user/agent interaction
• 		Human to human communication in virtual environments
• 		Standards and theoretical models for AI and/or VR
• 		Multimodal interaction and experiences in VR/AR

I believe that the AI & VR workshop will significantly contribute to the exploitation and dissemination of research and development results in AI, cybernetics, informatics, and virtual reality, help increase the professional level of its attendees and support their scientific work.

I would like to thank all attendees for their inspiring contributions, participation in the workshop and fruitful professional as well as informal discussions.

I wish you a pleasant time in Bratislava.

Bratislava, June 27, 2023

Assoc. Prof. Oto Haffner, PhD.
Technical Program Committee Chair

Workshop Program

Tuesday – 27 June, 2023

10:30 – 11:30	**Registration**
11:30	**Workshop Opening ((Meeting room PC303)**
11:45 Lunch	**Dining room, Tematínska 10**

12:30 – 15:00

A1 – Artificial Intelligence and Virtual Reality (Meeting room PC303)

Chairs: O. Haffner, J. Lacko

A1.1 POPULARIZATION OF STEM AND MECHATRONICS
Oto Haffner and Erik Kučera

A1.2 INFLUENCE OF AI-BASED NON-PLAYER CHARACTERS IN VIRTUAL REALITY FOR MEDICAL APPLICATIONS
Ján Lacko

A1.3 INTERACTIVE, VIRTUAL AND MIXED REALITY APPLICATIONS FOR EDUCATION AT INSTITUTE OF AUTOMOTIVE MECHATRONICS
Erik Kučera, Oto Haffner and Adam Móricz

A1.4 EXPOSURE THERAPY USING VIRTUAL AND MIXED REALITY
Dominik Janecký, Erik Kučera and Oto Haffner

A1.5 DIGITAL TWIN OF THE PRODUCTION LINE IN TIA PORTAL, UNITY AND GAME4AUTOMATION FRAMEWORK
Michal Balla, Oto Haffner, Erik Kučera and Ján Cigánek

15:00 – 15:30	**Coffee Break**
15:30	**Workshop Closing**

POPULARIZATION OF STEM AND MECHATRONICS

Oto Haffner and Erik Kučera

Abstract:

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Mechatronics combines mechanics, informatics, electronics, and automation. However, many mistakenly view it as just mechanics and electronics. This misconception hinders education and industry. Industry 4.0 encompasses automation, data exchange, and advanced manufacturing. Despite its potential, few high school students choose to study mechatronics due to outdated perceptions. To address this, the authors propose an original approach: a fan film inspired by Avengers: Infinity War to showcase mechatronics' modernity and captivate young minds.

◤ Introduction

In the past, the industry was influenced by innovation and technological change. These paradigms are called industrial revolutions. They were caused by mechanization (first industrial revolution), use of electrical energy (2nd industrial revolution) and electronics and automation (3rd industrial revolution). All mentioned industrial revolutions did not influence only the production itself, but also the labour market and the educational systems as well. As a result of these changes some jobs and professions disappeared. Now, due to the development of digitalization and robotics, we are facing the next industrial revolution, known as the Industry 4.0. It is expected that some jobs will be replaced. The emerging technologies have enormous effect on the education of people. Only competent and highly educated employees will be able to control mentioned technologies. The industry should cooperate with universities. The main vision of Industry 4.0 is the emergence of "smart factories", that will be connected to the production facilities with Cyber-physical systems called CPS. Using of the Internet of Things, the Internet of Services and the Internet of People will make connection: machine-machine, Fig. 1. Modern technologies for Industry 4.0 [4] human-machine or human-human, and at the same time an enormous amount of data will be obtained [1]. For this reason it will be necessary to analyse large data (Big Data) to be able to predict possible failures and adapt in real time to the changed conditions [2].

Now, let's analyse the Industry 4.0 impact on mechatronics. This should include the state-of-the-art in research, education and development of control methods, control structures, information a communications technology. Their applications in different types of industrial processes with the focus on mechatronic systems and the new trends declared in Industry 4.0 should be considered, as well [3]. Mechatronics merges methodology and basic principles of 4 close scientific disciplines: automation, information and communication technologies (ICT), electronics and mechanics. So it represents an exceptional example of a

multidisciplinary engineering and points out how an integration of disciplines leads to new degrees of freedom in the corresponding new methods of education [3] [5]. Multidisciplinary education in mechatronics for Industry 4.0 qualifies an engineer to perform initial design work in electrical, mechanical, automation, control engineering and information technologies and to communicate effectively with specialized design engineers in different disciplines (electrical, mechanical, power, ICT, etc.).
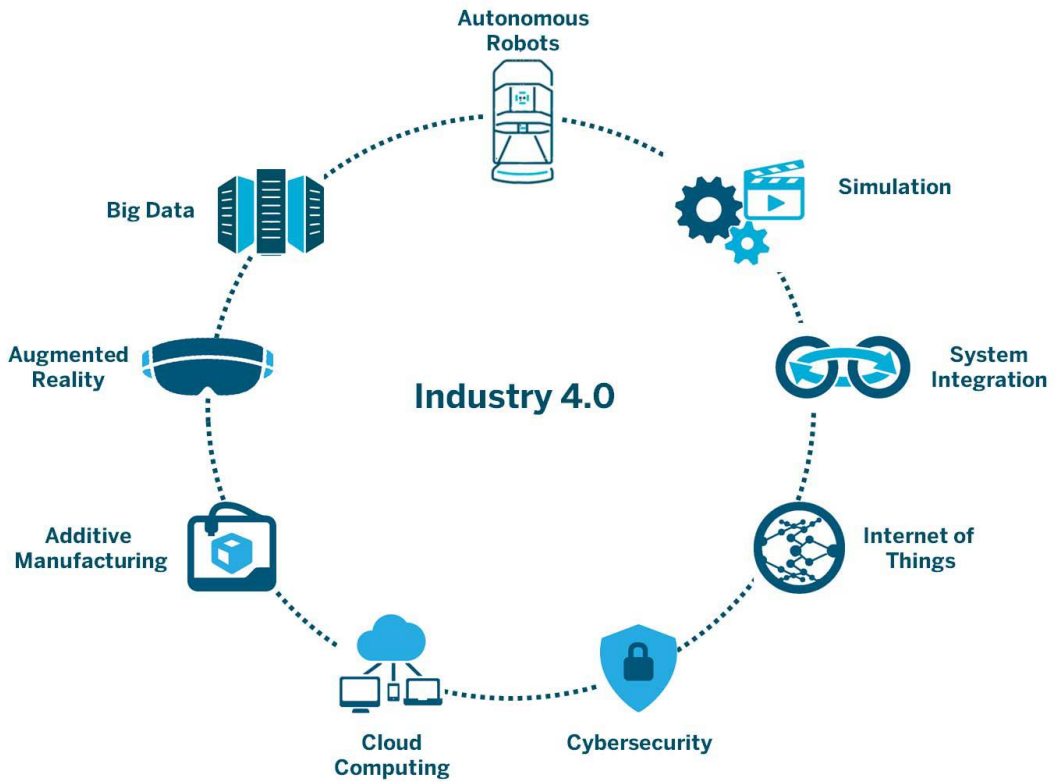

Fig. 1 Modern technologies for Industry 4.0 [4]

Universities need to profile their engineering curricula to better prepare students for professional practice [3]. Nowadays, modern technologies such as artificial intelligence, Internet of Things, cloud, computing virtual, mixed and augmented reality, etc., are used in mechatronics. According to the definition, mechatronics synergistically combines automation, mechanics, informatics and electronics into a single integrated whole (Fig. 2). To get a mechatronic device, the four fields and the individual components of the device have to be effectively interconnected; the binder are smart technologies. Still, smart technologies cannot be considered as a 5th extra field of mechatronics but rather a "soul" of the mechatronic product without which its individual components would not work as a whole.

Unfortunately, not many high school pupils would like to study mechatronics because young people are influenced by the obsolete perception of this field and does not see some of its new aspects. They do not perceive modern or information and communication technologies in this field. As it was stated, this is not true. The authors of the paper decided to present mechatronics as a modern branch in an innovative way.
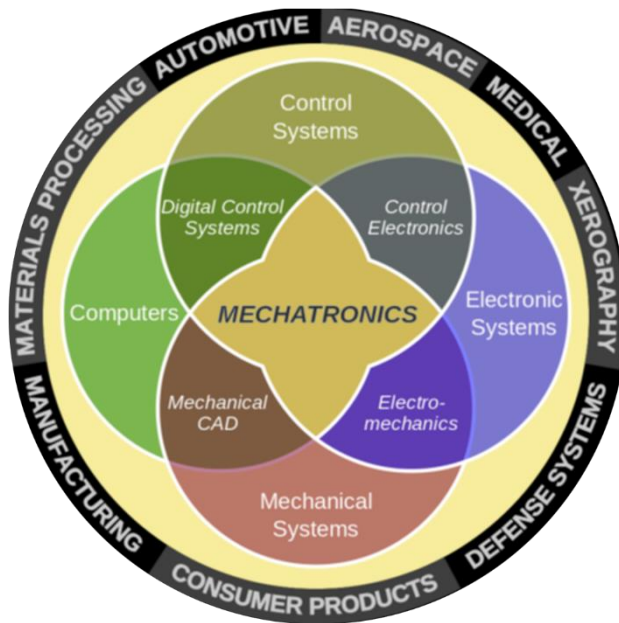
Fig. 2 Mechatronics diagram

◣ 1 Popularization Of Mechatronics Using Multimedia

The authors decided to inspire with the successful advertising videos of the universities that were inspired by the popular movie theme (Wolf from VUT - Wolf from Wall Street [6] or Join the FEI STU - Star Wars [7]. These days, multimedia or modern technologies are used in education or popularization of science and technology [8] [9] [10] [11] [12].

During polls for high school students and discussions, it was found that high school students do not know what exactly to imagine under the field of mechatronics. They have often lived with extremely old understanding of mechatronics as a combination of mechanics and electronics or electrical engineering. This is not mechatronics but electromechanics. It is therefore needed to draw the young generation's attention to this modern engineering field in a popular way with the expected viral effect. It is more and more challenging to take interest of the young generation (influenced by highbudget production of movies and series from Hollywood) in audiovisual work, and especially in education or science and technology. The more emphasis must be placed on the production quality. Today's young people are used to the highquality video and the above-mentioned high-budget production and will not be satisfied with the average audio-visual quality of the final product. So, the use of a well-known theme should support an interest in viewing such a work, which, however, must be processed at an adequate level.Text of each chapter has font size 10 and paragraphs with line spacing single. Indentiation of first line in paragraph is 1cm. Subchapters (subtitle bold, font size 10) are numbered 1.1 and 1.1.1 etc. The whole document has a Times New Roman font.

Page size of printed journal is B5 (176 x 250 mm). Side borders are 2 cm inside and 1.5 cm outside. Top and bottom border 1.5 cm. Even page is on the left side, odd page on the right side of printed journal. First page of every article is on the right side. Footnotes are allowed.

These days, multimedia or modern technologies are used in education or popularization of science and technology [8] [9] [10] [11] [12]. During polls for high school students and discussions, it was found that high school students do not know what exactly to imagine under the field of mechatronics. They have often lived with extremely old understanding of mechatronics as a combination of mechanics and electronics or electrical engineering. This is not mechatronics but electromechanics. It is therefore needed to draw the young generation's attention to this modern engineering field in a popular way with the expected viral effect. It is more and more challenging to take interest of the young generation (influenced by highbudget production of movies and series from Hollywood) in audiovisual work, and especially in education or science and technology. The more emphasis must be placed on the production quality. Today's young people are used to the highquality video and the above-mentioned high-budget production and will not be satisfied with the average audio-visual quality of the final product. So, the use of a well-known theme should support an interest in viewing such a work, which, however, must be processed at an adequate level.

The authors of the paper decided to make a fan film inspired by Avengers: Infinity War [13]. The purpose of the film is to introduce mechatronics to the young people in an attractive way as a modern 21st century discipline that combines informatics, mechanics, electronic systems and automation. In the fan film, the parallel between the aspects of the universe (= Infinity Stones from Avengers: Infinity War) and the 4 parts of mechatronics (= Mechatronics Stones) are used. The fifth stone is a source of tension and surprise moment. Many industrial and service equipment as well as consumer products are based on the combination of mechanical and electronic components. However, machines, equipment, devices and products become mechatronic only when they have some degree of "intelligence" as a result of the modern development of electronics, information-communication and control technologies (automation). As it was stated, to get a mechatronic device, the 4 fields and the individual components of the device have to be effectively interconnected; the binder are smart technologies. Consequently, the fifth stone represents smart technologies. Our fan film was named as Avengers: Five Mechatronics Stones (in Slovak: Avengeri: Päť kamenov mechatroniky). It has about 10 minutes.

When using pictures, they are centered relative to page column and their maximal width is the width of text column. Large pictures/tables may be rotated 90 degrees on the page. Printed version of this journal is black and white only - make all pictures contrast and comprehensible if no color is visible. Online journal keeps color contents and full details. A text inside of picture must be readable in print version.

◣ 2 Preproduction Of Fanfilm

The parallel between the Infinity Stones and the fields of mechatronics area came as a very interesting idea for a promotional video. The authors of the paper had filmed more promotional and educational videos at the Institute of Automotive Mechatronics at the Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava. But these videos were shorter and simpler. Thus, the story was written, and the screenplay was gradually developed and the filming started. Since the beginning, the authors have realized that this is their most comprehensive project in the last 10 years.

Challenges and restrictions:
• The use of personnel capital at the Institute - We wanted to make every element

of the fan film in-house. All members of team are from the mentioned Institute or other institutes of our faculty.

• Trying to cast girls - It was an enormous problem to find willing girl protagonists.

• The use of faculty spaces - They are often not representative and suitable for propagation and promotion.

• Time restrictions - It was recorded mainly when the semester lessons were not in progress. Even so, it was difficult to match the time schedules of the actors. One of the actors has to be added additionally using chromakeying techniques.

• Won't it be too long? - Should we keep the complete Marvel Cinematic Universe (MCU) movie structure (2 credits + mid-credits scene + after-credits scene)?

• "Zero" budget - The whole project had almost zero budget, colleagues helped us with the passion for work, we used only existing devices, laboratories, video editing software, etc. We only bought a few things inspired by the MCU. Our former PhD student is called Erich Stark (resembles Tony Stark in original films), so of course we used this name creatively. Over time, we realized that another of the PhD students was a bit like Captain America, so we also included this in the fan film.

We shot the fan film during 7 or 8 shooting days. Most of the time it took to prepare a thoughtful screenplay to fit everything together, and especially the very demanding postproduction, as the film contains many special visual effects. Preproduction started practically a few days after the premiere of Avengers: Infinity War. So the whole production lasted about 7-8 months during regular pedagogical and scientific work

◣ 3 Fanfilm Analysis

The described fan film can be seen here (English subtitles can be turned on): https://youtu.be/RtROkZqU6ns or http://avengers.mechatronika.cool/.

A Introduction in space

During the introduction, by microphone voice individual Mechatronics Stones are explained and also what is mechatronics.

B Why do we need Mechatronics Stones?

The main idea of the film is to use stones to make the mechatronic device work. As a device, a mechatronic vehicle model (RC model) was selected (Fig. 3). Five Mechatronics Stones have to be inserted into the virtual slots (Fig. 4). The slots have been filmed using chroma-keying techniques (Fig. 5).
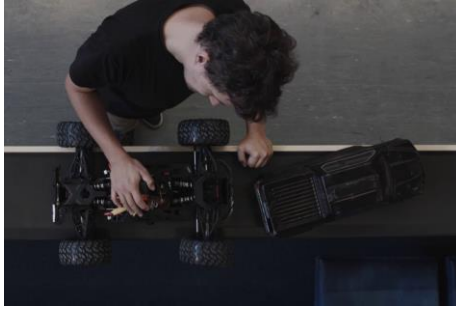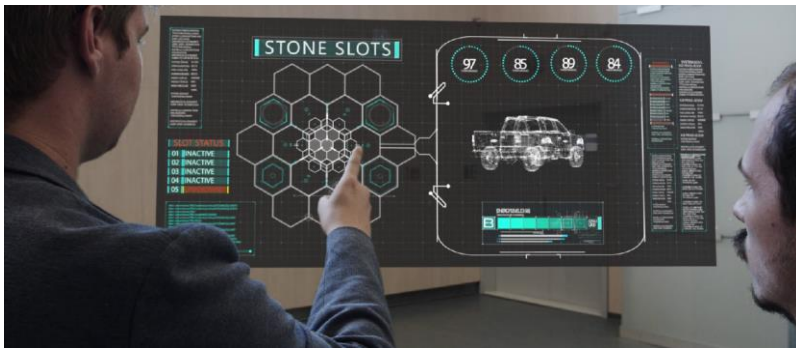
Fig. 3 RC model of car

Fig. 4 Slots of Mechatronics Stones

Fig. 5 Green screen for chroma-keying

C Electronics Stone

The first stone to be introduced is Electronics Stone (Fig. 7). This part shows the work with electronics (Fig. 6). The result of the work with electronics is a programmable LED cube.
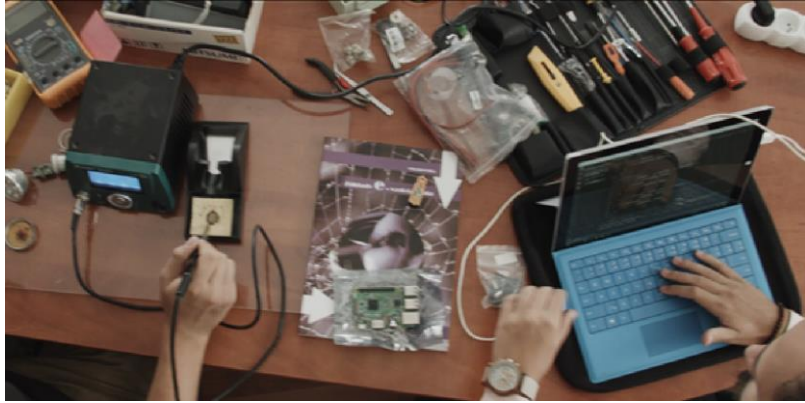
Fig. 6 The work with electronics

Fig. 7 Electronics Stone

D Mechanics Stone

The second stone is the Mechanics Stone. It is inspired by the Time Stone from original movies. Using the Mechanics Stone, a device is constructed (Fig. 8). At our workplace, the displayed device is really available (Fig. 9).
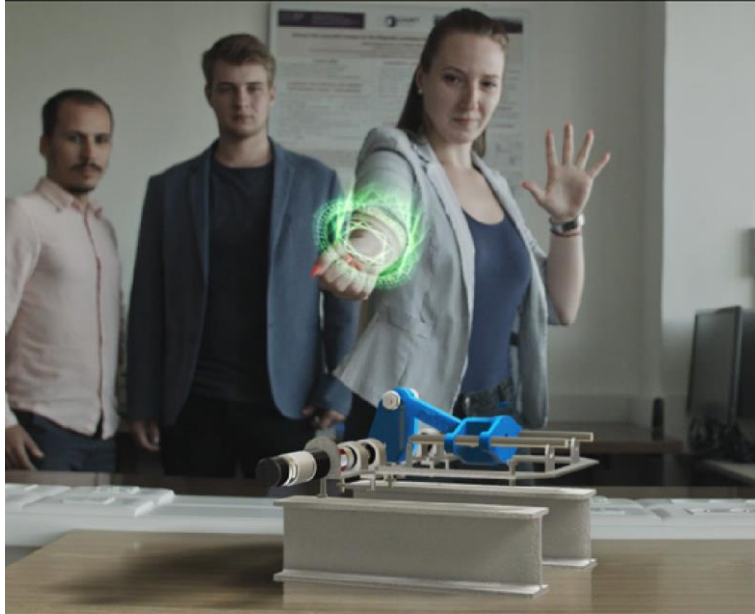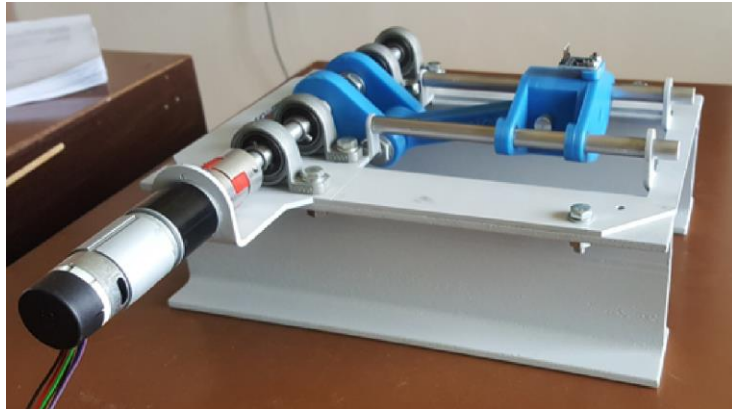
Fig. 8 The use of Mechanics Stone

Fig. 9 The real mechanical device

E Informatics Stone

The third stone is the Informatics Stone. Our PhD student - Erich Stark (Fig. 11) - is introduced. Informatics is presented by mixed / augmented reality and by holographic device Microsoft HoloLens (10).

F Automation Stone

The last part of mechatronics is automation or automatic control. Automation is presented by a model of magnetic levitation (Fig. 12). The Automation Stone is hidden in a ball controlled by magnets (Fig. 13).

Fig. 10 Microsoft HoloLens and augmented / mixed reality

Fig. 11 Iconic shot of Erich Stark inspired by Iron Man
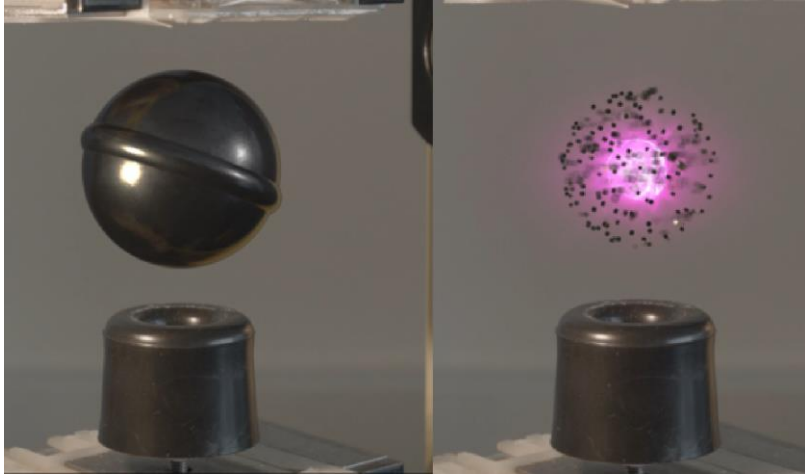

Fig. 12 Magnetic levitation model

Fig. 13 Automation Stone

Fig. 14 The device does not work

Fig. 15 Smart technologies Stone is located in glasses

Fig. 16 All Mechatronics Stones
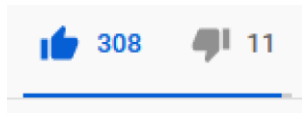

Fig. 17 Mid-credits scene

Fig. 18 Likes and dislikes on YouTube (03/01/2020)

G Smart Technologies Stone

The protagonists found that with four Mechatronics Stones the device did not work (Fig. 14). Smart technologies are needed to link fields of mechatronics. Smart technologies Stone is located in glasses (Fig. 15) of a new hero. Glasses are a symbol of intelligence. The stones are joined and the device works (Fig. 16).

H Smart Technologies Stone

The new hero turns to be an antagonist. He use the stones and snaps his fingers. Then our protagonists are turned into the dust (Fig. 17).

► 4 Critical Response

The described fanfilm achieved critical success (Fig. 18). It has about 15,000 views on 03/01/2020 on YouTube. Many Slovak media published articles about fanfilm: Nový Čas (online and print) [14], Refresher [15], Start it up [16], etc. Also, about fanfilm was written abroad [17].

► 5 Future work

We were surprised that the feedback was overwhelmingly positive. The audience is demanding and often does not take into account that Slovak films have much lower budgets than American films. Fanilms (like ours) usually have zero budgets, so actors and creators work out of enthusiasm for the thing. The viewer, and especially the young viewer, is influenced by the high-budget production of films and series from abroad. Since the fan film was a great success for the audience, we have practically finished the second part. The story began to emerge a few days before the premiere of Captain Marvel, which was early March 2019, and subsequently brought many inspirations. Thus, the preparation of the story and screenplay continued successfully. Following the premiere of Avengers: Endgame at the end of April 2019, the elements of the film were successfully included in the screenplay. And the main skeleton was done.

A new element will be the appeal that the study of mechatronics (and the study of technology in general) is also suitable for girls. The requirement to present technical disciplines as an attractive application not only for boys but also for girls came during our popularization mission at the institute from various sides - from high school students, students, teachers, including media communication experts. This is often solved by hiring actresses and promotional materials that are full of girls. However, this is unnatural, and such materials are more of a mockery, as they are not anchored in reality. In this case, it is necessary to be authentic and to promote real girl students. Candidates can then identify with the actresses.

We also cooperate with the STUBA Green Team university organization. It will be featured by our student, who is a member. Cooperation with this organization will certainly enrich the whole work qualitatively

◤ Conclusion

Multidisciplinary education in mechatronics for Industry 4.0 qualifies an engineer to perform initial design work in automation, mechanical, electrical, control engineering and information technologies and to communicate effectively with specialized design engineers in different disciplines (mechanical, ICT, electrical, power, etc.). These days, modern technologies such as cloud, artificial intelligence, Internet of Things, virtual, augmented and mixed reality, etc., are used in mechatronics. Unfortunately, not many of high school pupils would like to study mechatronics because young people is influenced by the old perception of this field and does not see some of its new aspects. The authors of the paper decided to present mechatronics as a modern branch in an original way - by the fan film inspired by Avengers: Infinity War. The described popularization fan film achieved critical success and appeared in mass media.
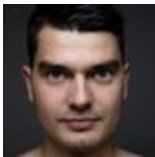
◤ Acknowledgment

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INFLUENCE OF AI-BASED NON-PLAYER CHARACTERS IN VIRTUAL REALITY FOR MEDICAL APPLICATIONS

Ján Lacko

Abstract:

Virtual Reality (VR) combined with Artificial Intelligence (AI) has opened new avenues for medical applications, revolutionizing the way healthcare professionals train, diagnose, and treat patients. Non-Player Characters (NPCs) play a crucial role in enhancing the realism and interactivity of VR environments. This article explores the influence of AI-based NPCs in VR for medical applications, focusing on their impact on medical education, surgical training, patient rehabilitation, and therapy. We discuss the benefits, challenges, and ethical considerations associated with AI-driven NPCs in medical VR. Through an examination of relevant research studies and real-world applications, this article aims to shed light on the transformative potential of AI-based NPCs in shaping the future of healthcare.

◣ Introduction

Virtual Reality (VR) has emerged as a transformative technology with applications across various industries, including healthcare. In the medical field, VR enables healthcare professionals to simulate realistic scenarios, engage in immersive training, and provide more personalized care to patients. The integration of Artificial Intelligence (AI) into VR environments [1] has further enhanced the potential of this technology by introducing AI-driven Non-Player Characters (NPCs) [2] that interact with users, providing realistic simulations, feedback, and guidance.

AI-based NPCs serve as virtual entities within VR environments, mimicking real-life interactions and behaviors. These intelligent NPCs can be programmed to exhibit human-like responses, enabling healthcare professionals to engage in realistic training scenarios, conduct accurate diagnoses, and design effective treatment plans. By leveraging AI algorithms, these NPCs can analyze user input, assess performance, and deliver personalized feedback, enhancing the educational and therapeutic value of medical VR experiences.

◣ 1 NPC in medical domain

Non-Player Characters (NPCs) have gained significant attention in the medical domain due to their potential to enhance various aspects of patient care and healthcare delivery. NPCs in the medical domain refer to virtual characters that interact with patients or healthcare professionals in virtual environments or simulation-based training. These NPCs

can provide guidance, support, and personalized experiences, contributing to improved patient engagement, enhanced training outcomes, and more efficient healthcare processes. The integration of NPCs in the medical domain holds promise for revolutionizing healthcare education, training, and patient-centered care.

A. AI-Based NPCs in Medical Education

One area greatly influenced by AI-driven NPCs in medical VR is medical education. Traditional medical education relies on lectures, textbooks, and limited practical experiences. However, VR with AI-based NPCs offers a more immersive and interactive learning environment [3]. Medical students and professionals can explore virtual anatomy and physiology [4], interact with virtual patients, and practice diagnostic skills in simulated scenarios. AI-driven NPCs can simulate patient cases with varying symptoms, allowing learners to develop critical thinking, diagnostic reasoning, and communication skills in a controlled and safe environment.

B. AI-Based NPCs in Surgical Training

Surgical training is another domain benefiting from AI-driven NPCs in VR. Surgeons can practice complex procedures and gain experience through virtual simulations [5] that closely resemble real surgical environments. AI-based NPCs can provide real-time guidance, evaluate performance, and offer personalized feedback, enabling surgeons to refine their techniques and decision-making abilities. Additionally, these NPCs can simulate team dynamics, enhancing teamwork and communication skills crucial in surgical settings.

C. AI-Based NPCs in Patient Rehabilitation

AI-driven NPCs are transforming the field of patient rehabilitation. Virtual reality environments combined with AI allow for interactive therapy sessions that engage patients in immersive exercises and activities [6]. NPCs can adapt the therapy experience to the individual's needs, monitor progress, and provide motivational feedback. This combination of AI and VR creates a more engaging and personalized rehabilitation experience, improving patient outcomes and adherence to treatment plans.

D. AI-Based NPCs in Therapy

AI-driven NPCs are also being utilized in therapeutic settings to enhance mental health interventions. Virtual reality environments can simulate various scenarios and situations, allowing therapists to expose patients to controlled and immersive environments that address specific phobias, anxieties, or traumatic experiences [7]. AI-based NPCs can provide real-time emotional recognition and tailored feedback, aiding therapists in delivering personalized and adaptive therapy sessions.

◤ 2 Properties of non-player characters in virtual reality

The properties of NPCs in VR contribute to the overall effectiveness and engagement of the user experience. In this section, we explore the key properties of NPCs in VR and their significance in creating compelling and lifelike virtual environments.

2.1 Behavior and Intelligence

One of the key properties that make NPCs in VR impactful is their behavior and intelligence. NPCs are designed to exhibit human-like behaviors, enabling realistic

interactions and enhancing the overall immersion and engagement of users in the virtual world. The behavior and intelligence of NPCs are crucial in creating dynamic and responsive virtual environments that effectively simulate real-world scenarios.

Decision-Making and Movement:

NPCs in VR possess algorithms that enable them to make decisions and move autonomously within the virtual environment. These algorithms determine the NPC's actions, reactions, and navigation patterns. Advanced AI techniques, such as rule-based systems, decision trees, or more complex machine learning algorithms, are employed to imbue NPCs with intelligent decision-making capabilities. This allows NPCs to respond to user input, adapt to changing situations, and navigate the virtual world in a realistic and believable manner. NPCs with sophisticated decision-making abilities can enhance the realism of VR scenarios and create more dynamic and interactive experiences.

Emotional Intelligence:

NPCs can be programmed with algorithms that allow them to recognize and respond to users' emotions. By analyzing facial expressions, voice tone, or other physiological cues, NPCs can adapt their behavior and responses accordingly. Emotional intelligence in NPCs enables more personalized and empathetic interactions, enhancing the user's sense of connection and immersion in the virtual environment.

Learning and Adaptation:

NPCs in VR can possess learning and adaptation capabilities, allowing them to improve their performance and behavior over time. Machine learning algorithms, such as reinforcement learning or neural networks, can be employed to enable NPCs [8] to learn from user interactions, user feedback, or other sources of data. NPCs can adapt their behaviors, decision-making processes, or communication styles based on the accumulated knowledge and experiences.

Cooperative and Competitive Behaviors:

NPCs in VR can exhibit cooperative or competitive behaviors, depending on the context of the virtual scenario. Cooperative NPCs can collaborate with the user or other NPCs, engaging in teamwork, providing assistance, or working towards shared objectives. Competitive NPCs, on the other hand, can act as adversaries or opponents, challenging the user's skills and stimulating engagement.

2.2 Interaction and Communication:

NPCs are designed to interact and communicate with users, providing a sense of presence, responsiveness, and interactivity. In this section, we delve deeper into the importance and significance of interaction and communication in NPCs within the VR context.

Natural Language Processing:

NPCs can understand and respond to user queries, commands, or statements, allowing for meaningful conversations. NLP algorithms enable NPCs to process and interpret natural language input, recognize speech patterns, and generate appropriate responses [9]. By leveraging NLP techniques, NPCs can engage in dynamic dialogue with users, providing

information, guidance, or engaging in interactive scenarios. Natural language processing contributes to the overall immersion and realism of the VR experience, as users can interact with NPCs using natural language inputs.

Gesture Recognition and Body Language:

NPCs can also recognize and respond to user gestures, body language, and non-verbal cues. Gesture recognition algorithms analyze the user's hand movements, gestures, or body posture to interpret their intentions or emotional states. NPCs can mirror these gestures or respond appropriately, creating a more immersive and realistic interaction. Body language recognition algorithms enable NPCs to interpret the user's body movements, facial expressions, and eye contact, allowing for more natural and nuanced communication.

Multimodal Feedback:

Interaction and communication with NPCs in VR can involve various sensory modalities, including visual, auditory, and haptic feedback. NPCs can provide users with visual cues, such as facial expressions, gestures, or text-based responses, to enhance understanding and convey emotions. Auditory feedback, including speech synthesis or ambient sounds, adds another layer of immersion and realism to the communication process. NPCs can also utilize haptic feedback, such as vibrations or tactile sensations, to simulate physical contact or provide feedback during interactions. Multimodal feedback enriches the overall user experience, making interactions with NPCs in VR more engaging, immersive, and intuitive.

2.3 Realism and Believability:

Realistic and believable NPCs enhance the user's sense of presence, engagement, and suspension of disbelief within the VR world.

Visual Realism:

NPCs are designed to have realistic appearances, textures, and animations that closely resemble their real-world counterparts. Advanced rendering techniques, such as high-resolution textures, detailed character models, and realistic lighting, contribute to the visual fidelity of NPCs. Accurate facial expressions, body movements, and gestures further enhance the visual realism, allowing users to perceive NPCs as lifelike entities within the virtual environment.

Environmental Realism:

NPCs in VR are not only influenced by their visual attributes but also by their interaction with the virtual environment. NPCs should respond realistically to their surroundings, whether it's navigating obstacles, interacting with objects, or reacting to dynamic changes in the environment. Realistic environmental interactions, such as realistic physics simulations, dynamic object interactions, and contextual behaviors, contribute to the overall believability of NPCs.

◣ 3 The evolution of AI-based NPCs

The evolution of AI-based Non-Player Characters (NPCs) in Virtual Reality (VR) for medical applications has progressed from basic position and movement to sophisticated gesture and facial expressions, natural language processing, and adaptive response to user

interaction. Initially limited to predefined positions, NPCs now exhibit realistic gestures and facial expressions, enhancing communication and emotional engagement. Integration of natural language processing enables NPCs to understand and respond to verbal commands, facilitating more natural and conversational interactions. NPCs have become adaptive, adjusting their behavior based on user interactions, improving the learning or therapeutic experience. Real-time emotional expression analysis allows NPCs to provide empathetic responses and aid in mental health interventions. With multi-modal interactions, NPCs combine verbal communication and non-verbal cues, enhancing communication effectiveness. These advancements contribute to the personalized and immersive experiences provided by AI-based NPCs in medical VR applications. Figure 1 shows the data processing interaction process for NPC using AI.

Furthermore, the context-awareness capabilities of AI-based NPCs enable them to interpret the virtual environment and user actions, providing more relevant and tailored responses. NPCs now incorporate machine learning techniques, allowing them to learn and adapt over time, refining their responses and improving their accuracy based on user interactions and feedback. The collaborative interactions enabled by AI-based NPCs facilitate teamwork, inter-professional communication, and realistic simulations within medical VR environments.
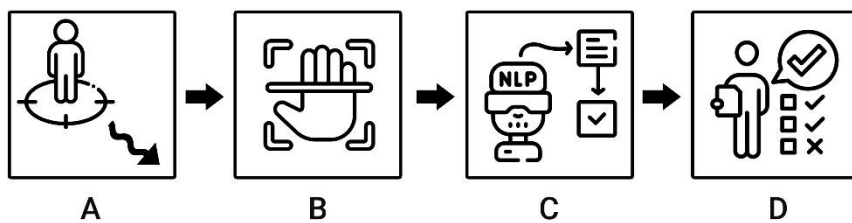

Fig.1. Data processing interaction procedure for NPCs using AI.
A - position and movement, B - gesture and facial expressions, C - natural language processing,
D - adaptive response to user interaction

◣ Conclusion

While the field of AI-based NPCs in medical VR has made significant progress, several challenges and considerations remain. Privacy and data security, ethical considerations surrounding the use of AI in medical decision-making, and the need for robust validation and evaluation of AI-driven NPCs are critical areas of focus. Future research directions include the development of more advanced AI algorithms capable of human-like responses, the integration of multimodal feedback systems (e.g., visual, auditory, haptic), and the exploration of AI-driven NPCs in areas such as patient counseling and telemedicine.

In conclusion, AI-based NPCs in VR have ushered in a new era of medical applications, revolutionizing medical education, surgical training, patient rehabilitation, and therapy. The state of the art in this area showcases the potential of AI-driven NPCs to enhance realism, interactivity, and personalization in medical VR experiences. Addressing challenges and ethical considerations while advancing research and.

◣   Acknowledgement

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INTERACTIVE, VIRTUAL AND MIXED REALITY APPLICATIONS FOR EDUCATION AT INSTITUTE OF AUTOMOTIVE MECHATRONICS

Erik Kučera, Oto Haffner and Adam Móricz

Abstract:

The main objective of the proposed project was to improve quality of teaching for graduates and specialists in technical study programs (Applied Mechatronics and Automotive Mechatronics) and related areas of automation using latest ICT technologies, virtual reality and interactive learning in modelling,

simulation and control. Visualization of the modelling and control processes of complex mechatronic systems, components and devices (e.g. cars, electric vehicles, mechatronic systems in consumer

electronics, health care, etc.) in virtual and mixed realities will give students more insight and better understand the studied stuff compared with conventional learning methods. The article summarizes selected applications developed in Unity engine at the Institute of Automotive Mechatronics, Faculty of Electrical Engineering and Information Technology STU in Bratislava.

Keywords:

virtual reality, mixed reality, Unity, modern education

ACM Computing Classification System:

Information systems, Information systems Applications

◤ Introduction

The development of new ICT technologies has allowed for the realization of contemporary kinds of visualization, such as interactive 3D apps [1], virtual reality, and augmented/mixed reality. In comparison to traditional educational approaches, the visualization of process modeling, identification, and control of complicated mechatronic systems, elements, and drives allows students to understand the studied subject considerably more quickly and thoroughly.

Nowadays, there is a trend of using 3D interactive applications and virtual/mixed reality in virtual tours for houses, cars, apartments and other products. Also, many modern interactive 3D applications for education are being developed [2] [3].

Automotive company Toyota offers modern 3D virtual showroom for their customers [4]. This 3D showroom was developed in Unreal Engine.

Additional interactive programs are available from Animech Technologies. Numerous educational modules are available from Animech Technologies, including Virtual Car, Virtual Truck, and Virtual Gearbox [5]. Students can comprehend the operation of the aforementioned devices using these interactive applications, as well as examine their interiors and dissect each component in depth.

A virtual clinic is a very interesting project [6]. The University of Miami or the Charles R. Drew University of Medicine and Science in Los Angeles, United States, are the sponsors of this online clinic. Students can practice diagnosing patients while learning how a larger clinic operates using this interactive program. As a result, they gain real-world experience working with the healthcare system while learning about it through virtual reality modeling and simulation.

Fig.1 Microsoft HoloLens - mixed reality application (Volvo) [8]

An absolute revolution was Microsoft HoloLens [7], the arrival of which has led to the emergence of a completely new segment of mixed reality. Mixed reality has unquestionable advantages over virtual reality, as the user perceives a real world and also a virtual world in the same moment. The use of this feature is in practice undisputed, and it is assumed that mixed reality is going to become a new standard in many areas such as marketing, modeling of complex mechatronic systems, education, etc. For Microsoft HoloLens there are many education and virtual tour applications.

Application 360-degree spatial video of historic locations like Rome or Peru is available through HoloTour [9]. The application provides additional holographic information about scene pieces or 3D models of significant landmarks that have not been preserved.

There are differences between virtual, augmented and mixed reality that should be explained.

Virtual reality (VR) replicates an environment that simulates a physical presence in places in the real world or an imagined world, allowing the user to interact in that world. Devices for virtual reality are HTC Vive, Oculus / Meta Quest, etc.

Augmented reality (AR) is a live, direct or indirect view of a physical, real-world environment whose elements are augmented (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data. Augmented reality is an overlay of content on the real world, but that content is not anchored to or part of it. The real-world content and the CG content are not able to respond to each other (Fig. 2 and Fig. 3).

Fig.2 Example of augmented reality

Fig.3 Example of augmented reality

Mixed reality (MR) is the merging of real and virtual worlds to produce new environments and visualisations where physical and digital objects co-exist and interact in real time. MR is an overlay of synthetic content on the real world that is anchored to and interacts with the real world. The key characteristic of MR is that the synthetic content and the real-world content are able to react to each other in real time. Technologies for mixed reality are Microsoft HoloLens (Windows Mixed Reality platform), Android ARCore and Apple ARKit.

Fig.4 Example of mixed reality

Fig.5 Example of mixed reality

◤ 1 Projects Description

    The main objective of the projects in Institute of Automotive Mechatronics aimed at VR and MR was to improve quality of teaching for graduates and specialists in technical study programs (Applied Mechatronics and Automotive Mechatronics) and related areas of automation using latest ICT technologies, virtual reality and interactive learning in modelling, simulation and control. Visualization of the modelling and control processes of complex mechatronic systems, components and devices (e.g cars, electric vehicles,

mechatronic systems in consumer electronics, health care, etc.) in virtual and mixed realities will give students more insight and better understand the studied stuff compared with conventional learning methods.

The projects' main objective was to introduce contemporary learning methods using multimedia-assisted education systems in the bachelor's and master's degree programs in the broad spectrum of mechatronics (Bc. - Automotive Mechatronics, MSc. - Applied Mechatronics and Electromobility), with a focus on the most recent findings in applied informatics, communication systems and technologies, automation, and other related fields. One of the main goals of the projects was to complete and modernize the multimedia laboratory for the teaching of mechatronics courses in bachelor's and master's programs using cutting-edge learning formats. These projects also developed interactive applications and teaching materials in virtual and mixed realities. Both in-person and online high school and university education will be able to use the planned educational resources and teaching strategies.

One of the outputs of the aforementioned projects was the creation of high-quality instructional and promotional movies from the subject area, which are now available on the cutting-edge e-learning website http://elearning.mechatronika.cool. The website has shown tremendous growth in popularity among students since its introduction. The produced videos won prizes at numerous film festivals, including CINEAMA.

The main goal of the projects that were mentioned was to expand on previous findings and apply methodological knowledge to develop learning applications for utterly novel learning forms in virtual and mixed worlds. On the aforementioned e-learning website, the generated applications were posted. The project's results will also be used to promote mechatronics and automation among the general public and secondary school students (dual types of mechatronics education), who may eventually enroll in technical universities, as well as in distance learning for practitioners in lifelong learning.

◣ 2 Projects Results and Description of Developed Applications

The projects' major objective was to develop contemporary, interactive 3D educational applications as well as virtual and mixed reality applications for mechatronics. The project's outputs can also be used to train professionals in lifelong learning and to make mechatronics and automation more accessible to the general public and high school students (dual forms of mechatronics education) — potential students at technical universities — since these materials will be made available to the general public. The project's secondary benefit was the development of methodological expertise for the production of engaging and appealing educational materials for mechatronics.

Both objectives and results of the projects can be divided into these points:

1) Workshops and popularization meetings / lectures
2) Interactive 3D applications and applications in virtual /
mixed reality from selected topics of mechatronics
3) Teaching improvement
4) Visualization of the new laboratory

Results are usually described on the modern e-learning website https://elearning.mechatronika.cool developed during the projects solution.

A. Workshops and popularization meetings / lectures

1) Meeting with students from the high school in Trenčín at the Institute of Automotive Mechatronics FEI STU

The meeting was held at the Institute of Automotive Mechatronics of the Faculty of Electrical Engineering and Information Technology of the Slovak Technical University in Bratislava (UAMT FEI STU). Within the area of virtual and mixed reality, the Microsoft HoloLens Mixed Reality Headset was presented to high school pupils. This meeting can be seen in Fig. 6.

Fig.6 Meeting with students from the high school at the Institute automotive

mechatronics FEI STU

2) Open Day FEI STU

The researchers presented their promotional and educational videos to visitors, and especially the Microsoft HoloLens Mixed Reality application "FEI STU Electric Cart", and also an interactive application for a computer with a showroom with electric vehicles created at the institute. This meeting can be seen in Fig. 7.

Fig.7 Open Day FEI STU

B. Interactive 3D applications and applications in virtual / mixed reality from selected topics of mechatronics

1) Meeting Solar System - interactive application for PC

Interactive educational application for web browser where you can see planets of our solar system.

Link: https://elearning.mechatronika.cool/blog/slnecnasustava/

2) Electric kart showroom + game - application for Samsung Gear VR and PC

This application presents the first electric kart developed in Slovakia. Applications also contains a simple game where the player can race with this kart - Fig. 8.

Link: https://elearning.mechatronika.cool/blog/elektromotokarahra-a-showroom-pc-gear-vr/
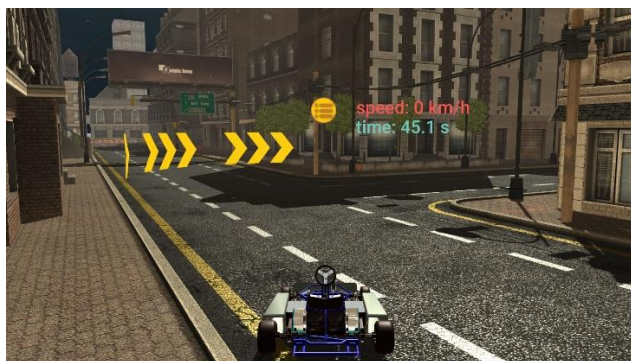
Fig.8 Electric kart showroom + game

3) Hangar with electric vehicles of the Institute of Automotive Mechatronics FEI STU - interactive application for PC

Application contains showroom (hangar) with electric kart, 6x6 rescue vehicle and also a promotional video with emobility projects of Institute of Automotive Mechatronics FEI STU - Fig. 9. User uses a mouse for control of this application like in 3D editors.

Link: https://elearning.mechatronika.cool/blog/hangar-selektrickymi-vozidlami-uamt-fei-stu-pc/

Fig.9 Hangar with electric vehicles - interactive application for PC

4) Electric vehicles showroom - application for PC and Oculus Rift

Interactive application for PC and virtual reality application for Oculus Rift headset. Application contains a showroom with electric kart (Fig. 10), 6x6 rescue vehicle. Application also contains a room with promotional and educational videos (Fig. 11).

Link: https://elearning.mechatronika.cool/blog/showrooms-elektrickymi-vozidlami-uamt-fei-stu-z-pohladu-prvej-osobypc-oculus-rift/

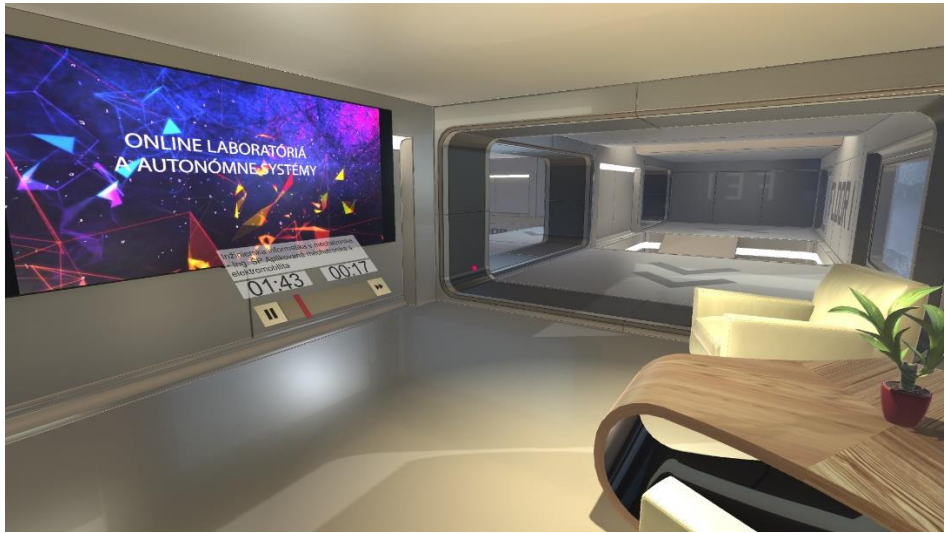Fig.10 Electric vehicles showroom - electric kart

Fig.11 Electric vehicles showroom – room with videos

5) FEI STU Electric Cart - mixed reality application for Microsoft HoloLens

Microsoft HoloLens application controlled by voice instructions. The user can see the electric kart model (Fig. 12 and Fig. 13) with a description of its parts. You can also see the GUI with information about other vehicles from institute and promotional video e-mobility. The application is available on the Microsoft Store.
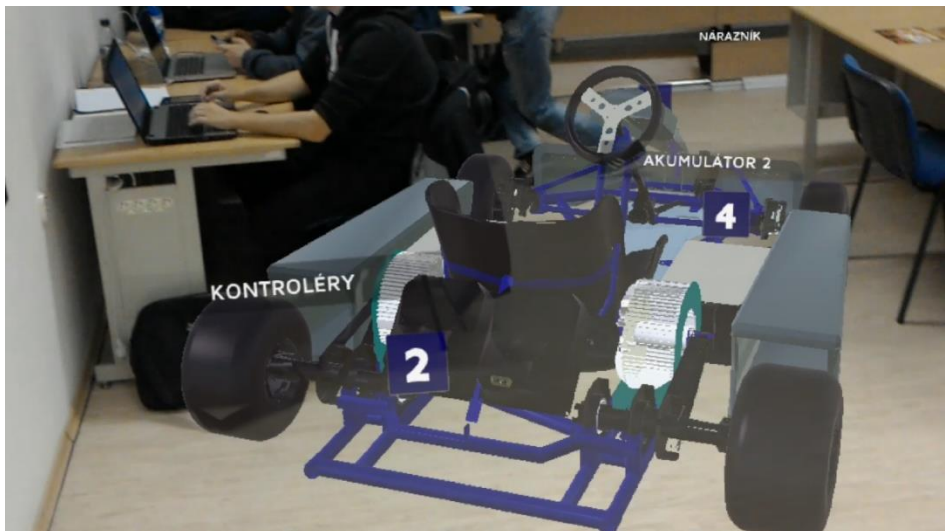
Link: https://www.microsoft.com/sk-sk/p/elektromotok%C3%A1ra-fei-stu/9p1nsd4prnsv
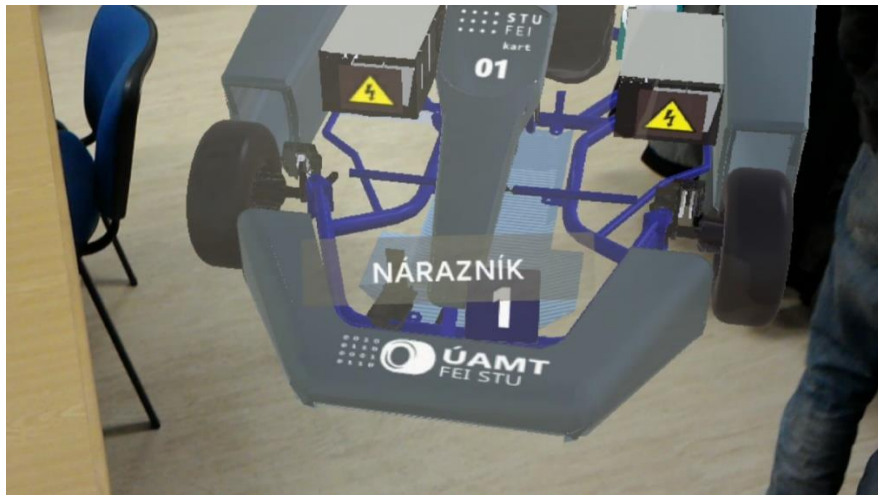

Fig.12 Microsoft HoloLens mixed reality application

Fig.13 Microsoft HoloLens mixed reality application

6) Interactive game for presentation of STUBA Green Team - PC, Universal Windows Platform, Xbox One

Presentation game for Windows operating system and Xbox One game console. The application was developed in collaboration with members of the STUBA Green Team. It includes a showroom with current and historical models of electric formulae developed and constructed by the team (Fig. 14). Furthermore, the app also includes a racing circuit where you can drive several electric formula models.

Link: https://elearning.mechatronika.cool/blog/prezentacna-interaktivna-hra-stuba-green-team-pc-universal-windows-platform-xbox-one/
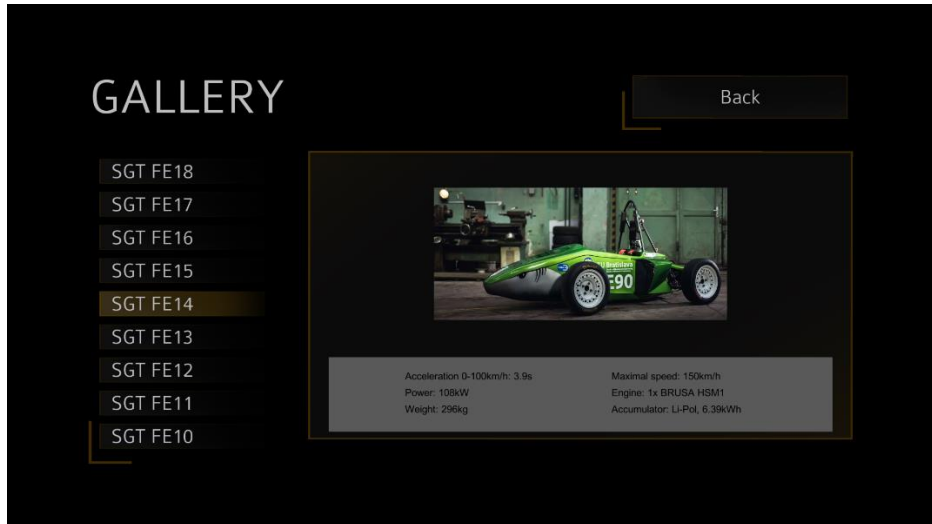
Fig.14 Interactive game for presentation of STUBA Green Team

7) Interactive game for object oriented programming teaching – PC

The aim of the work was to create an interactive educational application (game) to support the teaching of object-oriented programming basics. Practice has shown that understanding the principles of object-oriented programming is a very important factor in teaching this subject. For this reason, the game below was implemented using the Unity engine (Fig. 15).

Link: https://elearning.mechatronika.cool/blog/interaktivna-hra-pre-vyucbu-objektovo-orientovaneho-programovania/
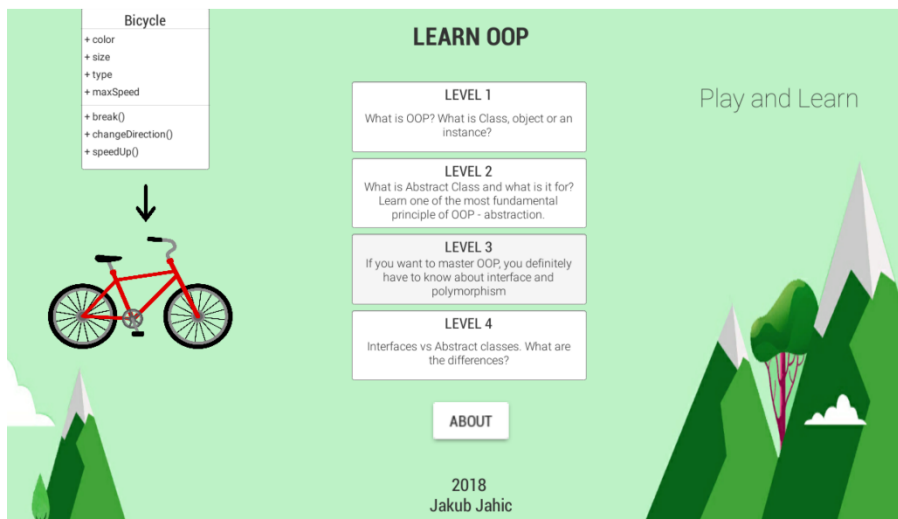

Fig.15 Interactive game for object oriented programming teaching

8) Interactive game for learning search algorithms and data structures - Android

Given the abstraction of the problem of algorithms and data structures, it is appropriate to introduce innovative solutions that can serve as an alternative means to teach and better understand the discipline. After analyzing the current issues and considering the requirements of this kind of project, the Unity engine was chosen to implement the application and target the Android mobile platform (Fig. 16). The interactive part of the application consists of two parts. The first is a competitive multiplayer game with themes related to data structures and algorithms. This part of the application is used to test knowledge in this area in the form of interactive tasks and quizzes. The second one is an open interactive space where the user can learn about the solved problem.

List of implemented algorithms

- Depth-first search algorithm

- Breadth-first search algorithm

- Kruskal's search algorithm

- Prim's algorithm

- Components find

- BubbleSort algorithm

- QuickSort algorithm

- MergeSort algorithm

- Djikstra's algorithm

List of implemented data structures

- Graph

- Binary tree

- Chained list

- Array

Link: https://elearning.mechatronika.cool/blog/interaktivna-hra-pre-vyucbu-prehladavacich-algoritmov-a-datovych-struktur/
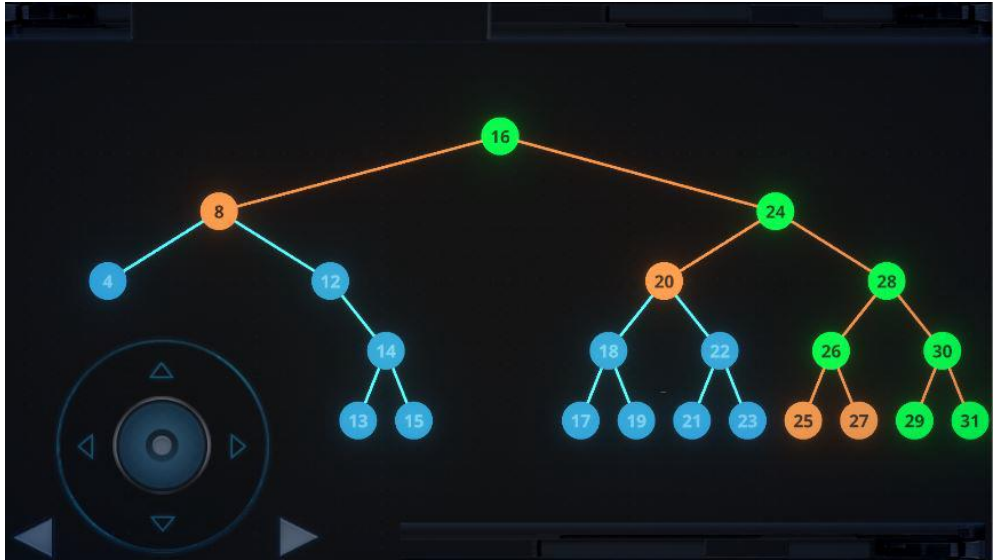
Fig.16 Interactive game for learning search algorithms and data structures

9) Hidden Threats of Internet - interactive game for PC

The game (Fig.17) with three levels guides users through the issue of working safely on the Internet. The Hidden Threats of Internet game is aimed at the general public, with an emphasis on primary and especially secondary schools. We believe that for this age group, which encounters the Internet most often, education about the pitfalls that commonly lurk for users is very important so that their trust and ignorance is not abused. At this age, the ability to understand the situation and detect dangers is still developing. Young people tend to be naive, not least because they do not have as much experience of the real world as adults.

The initial design of the game was created by Petra Kirschová, and a virtual reality version of the game was created as part of a team project. As part of Natália Klementová's master thesis solution, the game was reworked into a desktop version for the Windows operating system, which is hosted on this subpage. It is thus a version that is designed to be run on a classic monitor using common peripherals such as a mouse and keyboard.

The result was also supported by the KEGA project 026STU-4/2019 - Interactive showroom FINE - Photonics, Informatics, Nanotechnology and Electronics.

Link: https://elearning.mechatronika.cool/blog/skryte-hrozby-internetu-interaktivna-hra-pc/

Fig.17 Hidden Threats of Internet - interactive game for PC

10) World of Artificial Intelligence - VR learning application for HTC Vive

Based on the analysis of the requirements of practice and the experience of teaching students of applied mechatronics, it became clear that it is desirable to create educational games with the theme of intelligent technologies. A current phenomenon, which is also one of the pillars of the ongoing fourth industrial revolution Industry 4.0, is artificial intelligence. This topic is quite complex and the design had to take into account the target group to be targeted by the developed application. The orientation chosen was towards high school students and undergraduate students at universities. The aim of the game is to motivate them to take further interest in the discipline.

This educational game for virtual reality presents a course with 2 topics in the field of artificial intelligence. The first topic is decision trees and the second topic is artificial neural networks. Each is introduced by a single game level (level), with multiple parts and sub-tasks for each of them.

The game has been tested several times by a group of high school and college students and further modified based on the feedback.

The application was developed as part of Natália Klementová's master thesis.

The result was also supported by the KEGA project 026STU-4/2019 - Interactive showroom FINE - Photonics, Informatics, Nanotechnology and Electronics.

Link: https://elearning.mechatronika.cool/blog/svet-umelej-inteligencie-vyucbova-aplikacia-vo-virtualnej-realite-htc-vive/

Fig.18 World of Artificial Intelligence - VR learning application for HTC Vive

⬟ Conclusion

Virtual tours of homes, vehicles, furniture, and other things are increasingly adopting interactive 3D applications and virtual / mixed reality applications. The outcomes of projects that dealt with the creation of interactive 3D apps and virtual / mixed reality applications for mechatronics education are discussed in this paper. The projects' main objective was to introduce contemporary learning methods using multimedia-assisted education systems in the bachelor's and master's degree programs in the broad field of mechatronics (Bc. - Automotive Mechatronics, MSc. - Applied Mechatronics and Electromobility), with a focus on the most recent findings in applied informatics, communication systems and technologies, automation, and other related fields.

⬟ Acknowledgement

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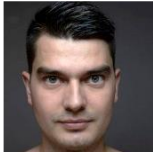Retrieved online, June 1, 2023

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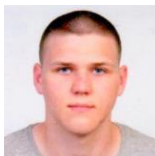
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EXPOSURE THERAPY USING VIRTUAL AND MIXED REALITY

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Abstract:

During their lifetime, almost everyone directly or indirectly encounters some manifestation of phobia or excessive fear and inappropriate reaction to certain stimuli. Those who do not suffer from phobia themselves certainly know someone who is limited by phobia in everyday life. In this work, an innovative education tool to manage fear caused by the phobia is presented. An important therapeutic phase is to teach a patient suffering from phobia to realize his fear and to handle this state. Virtual reality applications allow the client to be exposed to various extreme situations related to his/her phobia and observe his/her reactions in selected extreme situations. This allows for a more accurate identification of the level of phobia and the consequent improvement in patient coaching to manage phobia stress. The chapter presents the process of designing, developing, testing and implementing the VR application "PhoByeVR" and MR application "HoloPhoBye", which are intended for people suffering from phobias and will serve as an educational tool for better management of phobias. One application is fully compatible with HTC Vive and focuses on arachnophobia, ophidiophobia and acrophobia. Second application is fully compatible with Microsoft HoloLens and focuses on arachnophobia and ophidiophobia. For each phobia, it consists of 4 levels and a few other instructional scenes.

Keywords:

Virtual reality, Mixed reality, Exposure therapy, Phobias, VR application, MR application.

ACM Computing Classification System:

Visualization, Life and medical sciences, Modeling and simulation, Human computer interaction (HCI)

◤　Introduction

Fear, from an evolutionary perspective, is one of the oldest and strongest emotions. It belongs to automatic reactions and is divided into:
- Learned - it is evoked on the basis of an unpleasant experience that the person has gone through in the past.
- Innate - it is naturally encoded in the brain and is induced without previous experience [1].

Several parts of the human brain are used to perceive and react to fear. The thalamus is tasked with deciding where to send the information it receives from the ears, eyes, mouth and skin. The hippocampus is in charge of storing memories and processing stimuli based on context. During fear, an area in the brain called the amygdala is activated, which decodes emotions, stores frightening memories, and takes care of determining a possible threat. The amygdala sends a signal to the nervous system, and the hypothalamus takes care of the response to the stimulus that caused the fear. This reaction is a relic of evolution and is called fight or flight. The body, under direction from the hypothalamus, begins to release stress hormones, heart rate and blood pressure increase, and breathing quickens [1] [2].

⬛ 1 Anxiety Disorder and Fear

Fear is one of the most common reactions to various objects or events. However, if fear manifests itself to a disproportionate degree and begins to interfere with normal functioning and quality of life, we speak of an anxiety disorder, or in other words, a phobia. A phobia can simply be defined as an excessive fear of harmless objects or situations that persists for a sufficiently long period of time. In most cases, people with phobias are aware that their reactions to stimuli are exaggerated and the fear is irrational, but they feel that they cannot change this [3].

There are currently more than 600 different types of phobias. Practically speaking, it can be claimed that there is no situation, stimulus or object that could not trigger fear or even a phobia [4].

As described work focuses on the development of a virtual reality application that targets arachnophobia, ophidiophobia and acrophobia, these three phobias will be introduced and described in more detail in the following subchapters [4][5].

A. Arachnophobia

Arachnophobia is an exaggerated fear of coming into contact with a spider or other arachnid (e.g. scorpion). This term comes from the combination of two Greek words "arachne" - spider and "phobos" - fear. Fear of spiders and arachnids affects approximately 30 percent of the population. It is one of the most common anxiety disorders, and it is likely that this disorder is an evolutionary response, as venomous arachnids have always been associated with infections and disease [6][7].

B. Ophidiophobia

Ophidiophobia is a label for a panicky fear of snakes. The name ophidiophobia comes from a combination of two Greek words, the first being the word "ophis"- snake and the second being the word "phobos"- fear. Having a natural respect for snakes is normal. It is normal to be afraid of something that can kill you with one bite.

This reasoning was confirmed in 2013 by a study that claimed that the human brain is evolutionarily determined to be afraid of snakes, as snakes have always been a threat to its survival, especially in the days when there were no antivenoms [8].

The most common cause of ophidiophobia is evolutionary development, as we have already mentioned. This means that in the vast majority of cases it is congenital, but of course it can also be acquired during life [6][9].

◣ 2 Phobia Handling

It is a good idea to consult with a professional who is able to help people better manage their phobias or eliminate them altogether. The most effective methods in treatment are exposure therapy and cognitive behavioral therapy [10].

A. Exposure therapy

It is a type of therapy in which a person suffering from a phobia is exposed to   an object or situation that causes their fear. In this confrontation, the focus is on changing the person's reactions. Its main principle is the gradual, repeated exposure to increasingly challenging stimuli that trigger the phobia. For example, if a person has a fear of dogs, the therapy would progress from talking about dogs, to looking at pictures and videos, to a final confrontation with the dog. The confrontation itself could also be divided into parts, where the person would be further away from the dog, later close to the dog, and then, for example, have to pet the dog [10].

In this work, which focuses on the development of an application to better manage phobias, we used exposure therapy. Specifically, it is exposure therapy in virtual reality (VR).

B. Cognitive behavioral therapy

This type of therapy is based on precisely proven scientific principles and the precise identification of the symptoms that the treatment will seek to eliminate. A variety of techniques are used that the therapist tries to teach their clients. He teaches them how to evaluate their fear and the behaviors that result from it, teaches them how fear works and how to combat it effectively [11].

3   Description of Developed Application for Virtual Reality Exposure Therapy

This chapter will describe the process of designing and developing an application as a contribution in phobia management called "PhoByeVR".

The "PhoByeVR" application must meet several key requirements, such as:

- The application focuses on three types of phobias, namely arachnophobia, ophidiophobia and acrophobia.
- The core of the application consists of 4 main levels for each type of phobia. The difficulty of these levels gradually increases.
- More challenging levels consist of more scenes, thus further dividing the difficulty of the levels and achieving a better gradation of difficulty.
- An important part of the application is the relaxation scene, which serves two purposes. The first is to measure the participant's bodily functions in a calm environment to better evaluate the effectiveness of the app at more challenging levels. The second purpose is to relax the participant, if he/she becomes too stressed in a more challenging level, he/she will simply switch to this relaxation scene.
- The final version of the application will be fully compatible with HTC Vive.

The goal of the application is not to pass all levels in one session. The application is designed so that we can go through each level multiple times, in different ways. This is achieved by the participant completing each level in an increasingly courageous way, with more confidence and with more repressed fear.
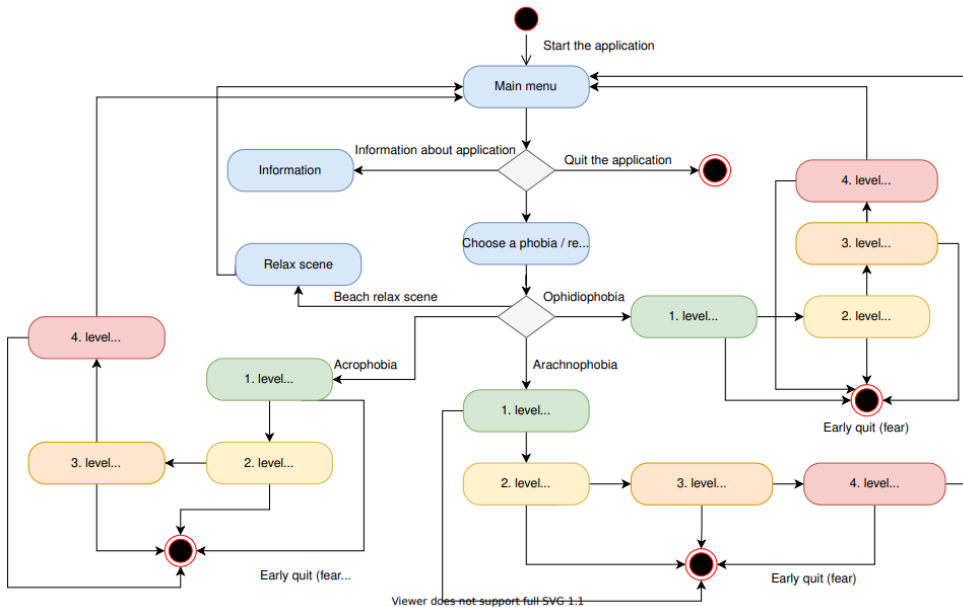

Fig. 1. UML State Diagram

A. Main Menu

After entering the application, the participant will find himself/herself in the main menu, where he can get to the control instructions, the app information, he/she can choose one of the three aforementioned phobias or he can get to the relaxation scene. The relaxation scene is designed to initially measure the participant's bodily functions in a calm environment, and its second purpose is to provide the participant with a calm scene to calm down during his phobia treatment in the different levels of the application.

Fig. 2. Menu scene

B. Relaxation scene

The participant finds himself on the beach during a beautiful sunset (Fig. 3). Relaxing music and the sounds of the sea make the stay more enjoyable. He/she can see birds flying in the sky, dolphins and sea turtles swimming in the sea. While at the beach, he/she can try catching and throwing various objects, such as coconuts that have fallen from palm trees, inflatable balls. Here the participant gets used to the ways of interacting in virtual reality. This scene is used at the beginning of the participant's sessions to measure the client's bodily functions in a calm environment, but at the same time the participant can return to this scene at any time if he/she is under a lot of stress in other scenes.

Fig. 3. Relaxing beach scene

C. First Level

After choosing one of the three phobias, the levels vary, some more, some less. In

the first level for each of the three phobias, the participant will be in a room full of different *photographs* and *paintings* on the walls, then there is a tablet and two TV screens on which he can play *videos*. Of course, the content of these videos and photos in the room depends on which phobia the participant has chosen.

Fig. 4. Level 1 – scene with photos and videos

D. Second Level

In the second level, the participant will be in a room that will give him/her access to scenes with 360° videos. The content of these 360° videos depends on which phobia the participant has chosen. Even though some of the videos may seem challenging, it is important to remember that these are still videos that the participant will just stand there and be able to pause, calm down, and then play them again at any time.

Fig.5. Level 2 – scene with 360° videos – therarium with snake and spide

Fig. 6. Level 2 – scene with 360° videos for fear of height

E. Third Level

The third level is characterized by the participant being confronted not only with photographs or videos, but with the environment in which he or she moves, along with 3D models of the objects he or she fears.

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The third level for arachnophobia and ophidiophobia takes place in the terrarium and storage room. There are 6 terrariums in the terrarium room where the participant will see snakes or spiders up close depending on which phobia they have chosen.

The third level for acrophobia is the climbing room, in which the participant has several obstacles to overcome. He must climb a high climbing wall, he must scramble over a large pit using a horizontal ladder, climb a high ladder and finally climb down a metal pole.

The third levels for all three phobias will already cause more or less difficulty even for those who were not very scared in the first and second levels and handled them quite easily.

Fig. 7. Level 3 – Therarium room with spiders and snakes

Fig. 8. Level 3 – Climbing room

F. Fourth Level

The fourth level is characterized by direct interaction with the object of fear.

In the fourth level for arachnophobia and ophidiophobia, the participant will be in a jungle where several spiders or snakes will be moving around and the participant's task will be to catch these snakes or spiders in bags. All these snakes and spiders look very realistic thanks to the animations, so it will be a new challenge for the participant.

The fourth level in acrophobia is a skyscraper, where the participant will have to get through the different floors of the skyscraper, where several challenging tasks await him. He/she will have to walk across a slab between two buildings, then through a large terrace with a glass floor or later he/she will have to walk through a narrow seam of the skyscraper.

Once all four levels have been passed, it is up to the participant to decide whether the phobia has been sufficiently suppressed, or whether we will have to arrange for further sessions where the

participant will be able to go through the levels in a more challenging way and as many times as he/she needs to suppress the phobia to a greater extent.

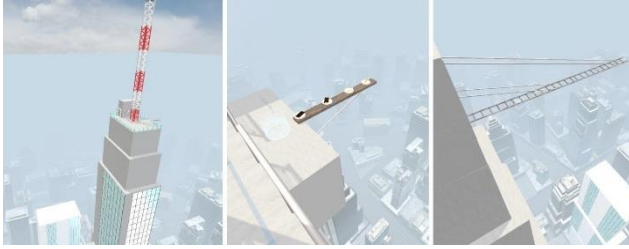Fig. 9. Level 4 – Jungle scene with spiders and snakes

Fig. 10. Level 4 – Therarium room with spiders and snakes

◤ 4 Description of Developed Application for Mixed Reality Exposure

This chapter describes the process of designing and developing an app as a contribution to phobia management called "HoloPhoByeMR".

The "HoloPhoByeMR" app must meet several key requirements, such as:

- The app targets two types of phobias, namely arachnophobia and ophidiophobia.
- The core of the application consists of 4 main levels for each type of phobia. The difficulty of these levels increases progressively.
- The most challenging level consists of multiple scenes, further dividing the difficulty of the level and achieving a better gradation of difficulty.
- The final version of the app will be fully compatible with Microsoft HoloLens2.
- The goal of the app is not to complete all levels in one session. The app is designed so that we can go through each level multiple times, in different ways. This is achieved by the participant completing each level in an increasingly courageous way, with more confidence and with more suppressed fear.

A. Main Menu

Upon entering the application, the participant is taken to the main menu where he/she can access control instructions, information about the application, and can select one of the two phobias listed above.
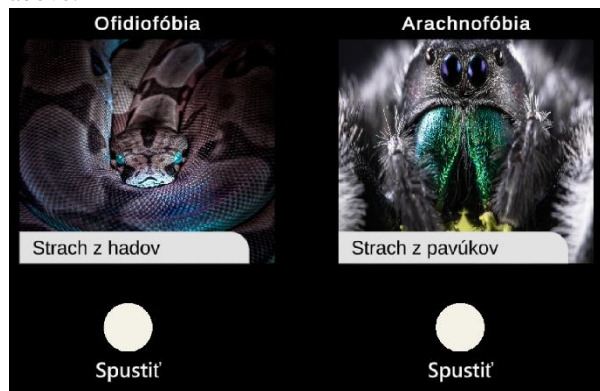

Fig. 11. Menu scene of MR application

B. First Level

After choosing one of the two phobias, the levels vary, some more, some less. In the first level for each phobia, the participant finds themselves in a room full of different photographs and images. In front of the user is a table on which there are several photographs for the user to look at. Furthermore, there is also a large picture in this room on which the user can change the content. The difficulty of this content gradually increases and each large image will become more and more annoying to the user. Basically, for both phobias, this level is the same except that the displayed content changes (i.e. the images change). From a technical point of view, I used the same prefabs, the same scripts, and the

only thing that changed in the scenes are the images that the prefabs and scripts were working with.
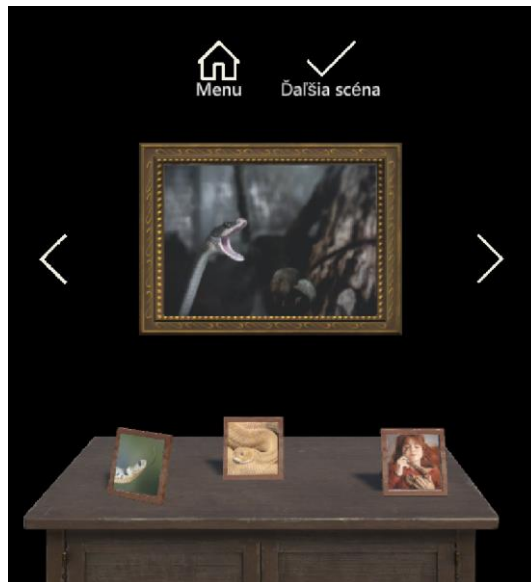

Fig. 11. Level 1 with pictures of snakes and spiders

C. **Second Level**

In the second level there is a chest of drawers with a TV in front of the user. With the help of AI the user can turn on the TV. A video with spiders/snakes will start playing on the TV. Also, the user can switch between multiple TV stations where there are snake/spider videos of multiple difficulties. Of course, in case of emergency, the user can also turn off the TV by pressing the same button with which he/she turned on the TV.

Basically, this level is the same for both phobias, only the content displayed changes (i.e. the videos change). From a technical standpoint, I used the same prefabs, the same scripts, and the only thing that changed in the scenes are the videos the prefabs and scripts used to work with.
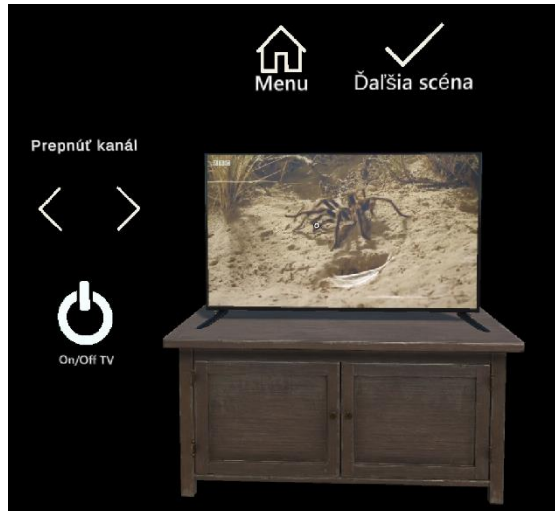
Fig. 12.Level 2 with videos of spiders and snakes

D. **Third Level**

The third level is a bit more difficult. It is not enough for the user to just look at pictures and videos, but he will have to interact with the 3D model, which will be much more challenging for him. In this level, there is a 3D hologram with a spider or snake in front of the user and an AI with which the user can interact with the scene. The user can switch between different snakes and can trigger their animations. At first the 3D model of the snake/spider will be in front of the user as a hologram, but when the user touches the snake/spider the 3D model will be in real colors.

Basically, this level is the same for both phobias, only the displayed content changes (i.e. the 3D models change). From a technical point of view, I used the same prefabs, the same scripts, and the only thing that changed in the scenes are the 3D models the prefabs and scripts used to work with.
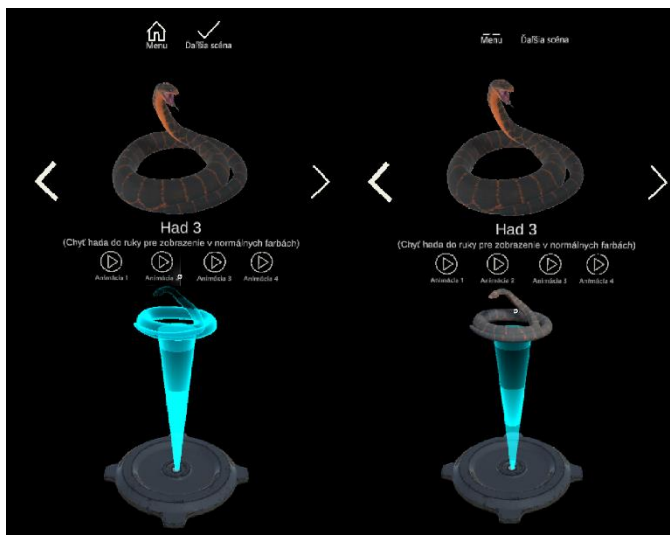
Fig. 13. Level 3 with 3D models of snakes and spiders

E. Fourth Level

The fourth level is divided into several parts, which gradually increase in difficulty. The main difference from the other levels is that this level uses the strongest feature of the mixed reality glasses, which is working with the user's real environment.

In the first sublevel of this level the user thoroughly scans the room around him. Once he has successfully scanned the room, he clicks on the "room scanned" button. When this button is clicked, the blue polygons that marked the scanned parts of the room will disappear and the sound of various snakes and spiders will be played in the user's ears. In this part we are trying to give the user the impression that there are snakes and spiders around him in the room, even though he cannot find them yet because there are none.

In the second sub-level of this part, when the user clicks on the "increase difficulty" button, several static 3D models of snakes or spiders will appear around the user. These 3D models can be placed arbitrarily around the user's room (in front of the user, behind the user, or even above or below the user).

In the third sub-level of this section, when the user clicks on the "increase difficulty" button, several moving 3D models of snakes or spiders will appear around the user, making annoying noises in

addition to the snakes or spiders. These 3D models can be placed anywhere in the user's room (in front of the user, behind the user, or even above or below the user).

Essentially, this level is the same for both phobias, only the content being displayed changes (i.e. the 3D models and sounds change). From a technical standpoint, I used the same prefabs, the same scripts, and the only things that changed in the scenes are the 3D models and sounds used that the prefabs and scripts were working with.

5 Testing and Case Studies of VR application

The work included not only the design and development of the application for phobia management, but also its testing in collaboration with participants who suffer from phobias. The ideal way to measure the effectiveness of the application is to record the participants' fear, which should steadily decrease as the number of sessions increases and participants should perform the tasks with much more courage and confidence. Such a measurement can be achieved in several ways, such as recording changes in heart rate, in the strength and intensity of breathing, but also, for example, in changes in skin conductance.

Mindfield eSense Skin Response device was used to measure skin conductance. Skin response is also known as galvanic skin response or electrodermal response and is measured in Siemens (µS). This device operates based on two electrodes that are connected via a microphone input to a mobile phone that actively measures a small, imperceptible voltage on the skin. All sweat glands on the human body are controlled by the nervous system and thus respond directly to the emotional, physical or psychological stimuli a person is currently experiencing.

PARTICIPANTS AND INTENSITY OF THEIR PHOBIA BEFORE SESSIONS

Participant	Phobia	Phobia intensity (1-10)
Participant No.1	Ophidiophobia	7
Participant No.2	Arachnophobia	6
Participant No.3	Acrophobia	6
Participant No.4	Acrophobia	9

A. Case Study: Participant No.1 – Ophidiophobia

During the first session at the first level, which is the room with pictures and videos, the participant was particularly uncomfortable with the large pictures on the walls and the videos on the TV screens, which he viewed from close In the first session, these were skin conductance values in the range of 4.3 - 8.8 SCR/MIN, symbolizing a slightly elevated level of fear.

In the second level, the participant was played three 360° videos of a python in a terrarium. At this level, the participant felt slightly increased fear during the second session. In the third scenario, when he was directly in the terrarium with the python, he experienced fear with a value of >13 SCR/MIN.

On the third level in the terrarium room, the participant felt only slightly increased fear most of the time during the fourth session. However, in the warehouse, where he came to a direct confrontation with the snake, his fear had already jumped up to 13 SCR/MIN (Fig. 18).

At level four during the fifth session, the participant experienced increased fear with values of 10-16.8 SCR/MIN (Fig. 19). Gradually after the initial snake catching interactions, this fear decreased slightly but still remained at intense levels.
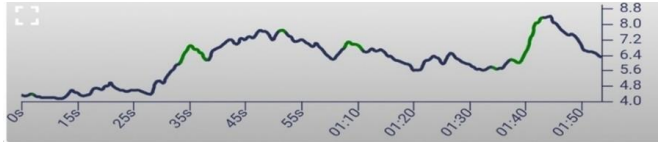
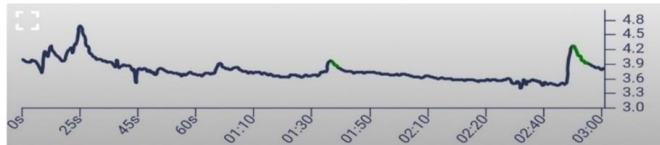Fig. 14. Participant No. 1 – Session 1 – Relaxation Scene

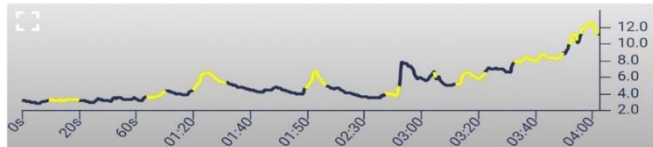Fig. 15. Participant No. 1 – Session 1 – First Level
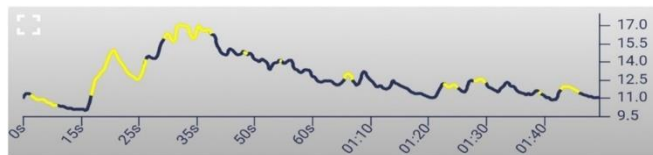
Fig. 16. Participant No. 1 – Session 4 – Third Level

Fig. 17. Participant No.2 – Session 5 – Fourth Level

SESSIONS WITH PARTICIPANT NO.1

Sessions	Pulse - Level 1	SCR - Level 1	Pulse - Level 2	SCR - Level 2	Pulse - Level 3	SCR - Level 3	Pulse - Level 4	SCR - Level 4
Session 1	78-84	4.3–8.8	-	-	-	-	-	-
Session 2	78-84	4.6–8.1	80-88	4.2–12.7	-	-	-	-
Session 3	75-80	4.1–7.4	80-89	4–12.8	-	-	-	-
Session 4	73-77	3.7–6.1	78-86	3.8–10.2	82-91	3.5-13	-	-
Session 5	-	-	74-81	3.6-7,9	83-90	4-12.8	85-95	10-16.8
Session 6	-	-	-	-	80-88	3.8-9.9	82-92	9.1-14.7
Session 7	-	-	-	-	75-81	3.6-7.9	80-87	8.4-11
Session 8	-	-	-	-	72-78	3.8-6.5	74-81	5.6-8.4

Case Study: Participant No.2 – Arachnophobia

In the first session in the room with pictures and videos, we found that the pictures on the table and the pictures on the walls did not impress the participant very much and achieved skin conductance of less than 5 SCR/MIN. When confronted with videos on TV screens and

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a tablet, the participant achieves slightly elevated skin conductance values up to 6.5 SCR/MIN.

In the second level, the participant played three 360° videos of a tarantula in a terrarium. At this level, the participant experienced slightly increased fear during the second session and had skin conductance of >9 SCR/MIN during the third scenario when she was directly in the terrarium with the tarantula.

In the third level in the terrarium room, the participant initially felt only slightly increased fear. The fear increased significantly after arriving at the storage room, where she had to find and catch a spider that had escaped from one of the spider containers. When confronted directly with the spider on the fourth encounter, the skin conductivity values were around 11 SCR/MIN.

In the fourth level, during the fifth session, the participant experienced increased distress of 10-13 SCR/MIN at certain stages. Values around 13 SCR were reached by the participant when confronted with a giant tarantula.

<center>SESSIONS WITH PARTICIPANT NO.2</center>

Sessions	Pulse - Level 1	SCR - Level 1	Pulse - Level 2	SCR - Level 2	Pulse - Level 3	SCR - Level 3	Pulse - Level 4	SCR - Level 4
Session 1	68-74	3.7–6.5	-	-	-	-	-	-
Session 2	68-70	3.8–5.8	72-79	4.1–8.8	-	-	-	-
Session 3	-	-	71-77	4.2–7.9	-	-	-	-
Session 4	-	-	69-74	3.8–6.7	75-83	4.8-11	-	-
Session 5	-	-	-	-	74-80	4.9-10.1	74-86	10-12.9
Session 6	-	-	-	-	69-76	4.1-7.9	72-81	8.4-11.2
Session 7	-	-	-	-	-	-	69-75	6.1-7.8

Case Study: Participant No.3 – Acrophobia

During the first session in the first level, which is the room with pictures and videos, the participant was particularly uncomfortable with the videos on TV screens and tablet. When viewing the pictures on the table and the pictures on the walls, the participant reached values up to 5 SCR/MIN, but with the videos these values increased up to 7.2 SCR/MIN and the heart rate was in the range of 70-76 beats per minute. Thus, in the first level, the participant was only achieving slightly elevated fear values and a slightly elevated heart rate.

In the second level, the participant was played three 360° videos of progressively increasing difficulty. At this level, the participant experienced intensely increased fear during the second session, and during the rope climbing over the canyon scenario, these values climbed up to 16.5 SCR/MIN.

In the third level in the climbing room, the participant felt intense fear most of the time during the fourth session. On the large climbing wall, this fear climbed to values of 21.5 SCR/MIN during falls, representing very intense fear.

In the fourth level in the skyscraper scenes during the fifth session, the participant felt very intense and high fear, where his skin conductance readings were in the range of up to 20-30 SCR/MIN and his heart rate ranged up to 115 beats per minute. Gradually, after several sessions and more time spent in these scenes, we were able to reduce his skin conductance to a maximum value of 14.6 SCR/MIN and his heart rate to values of 79-85 beats per minute.

Sessions	Pulse - Level 1	SCR - Level 1	Pulse - Level 2	SCR - Level 2	Pulse - Level 3	SCR - Level 3	Pulse - Level 4	SCR - Level 4
Session 1	70-76	3.5–7.2	-	-	-	-	-	-
Session 2	71-78	4.1–6.5	80-91	6.4–16.5	-	-	-	-
Session 3	68-75	3.9–5.8	81-88	7.1–11.8	-	-	-	-
Session 4	65-70	3.2–5.1	76-82	5.8–9.2	77-98	4.8-21.5	-	-
Session 5	-	-	71-78	4.6-6.4	79-91	4.1-15.8	90-115	20-30
Session 6	-	-	-	-	75-86	3.7-9.6	86-101	14-24.3
Session 7	-	-	-	-	71-80	3.7-7.1	84-94	9.9-21.7
Session 8	-	-	-	-	-	-	81-90	8.6-19.6
Session 9	-	-	-	-	-	-	81-88	7.1-15.8
Session 10	-	-	-	-	-	-	79-85	6.4-14.6

6 Testing and Case Studies of MR Application

The work involved not only designing and developing a phobia management app, but also testing it in collaboration with participants who suffer from phobias. Measuring the effectiveness of the app can be achieved in a number of ways, for example by recording changes in heart rate, breathing force and intensity, as well as changes in skin conductance, for example.

To measure skin conductance we again use the Mindfield eSense Skin Response device. Skin response is also known as galvanic skin response or electrodermal response and is measured in Siemens (µS).

Currently, this application is only in the early stages of testing, where we had a large sample of different test subjects, some of whom suffered from phobia and others who did not, and served as a control sample.

We are currently running further sessions and further testing of the app and therefore cannot present any results yet as they would not be relevant. We hope to be able to provide full information on the results of the testing soon.

◣ Conclusion

This study focused on the development of virtual and mixed reality as a therapeutic method for treating phobias. We designed and developed the VR application "PhoByeVR" and the MR application "HoloPhoBye" as educational tools to better manage phobias. The applications specifically target phobias such as arachnophobia, ophidiophobia, and acrophobia. They offer multiple levels of exposure, allowing individuals to gradually confront their fears in a controlled and immersive environment. Our research shows promising results in using VR and MR as effective interventions for phobia treatment. Further studies and advancements in technology can continue to enhance the effectiveness and accessibility of these therapeutic approaches.

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DIGITAL TWIN OF THE PRODUCTION LINE IN TIA PORTAL, UNITY AND GAME4AUTOMATION FRAMEWORK

Michal Balla, Oto Haffner, Erik Kučera and Ján Cigánek

Abstract:

The fourth industrial revolution is currently unfolding in the industry, marked by the integration of advanced technologies like artificial intelligence, the Internet of Things, and big data. Among the significant pillars of this revolution, digital twin technology is gaining rapid importance across diverse industries. However, the concept of digital twins is frequently misunderstood or used as a buzzword, causing confusion regarding its definition and practical applications. Recognizing this issue, the authors of this paper were motivated to develop their own demonstration applications that enable the control of both real and virtual systems through automatic two-way communication and mutual influence within the context of digital twins. The objective of this paper is to showcase the utilization of digital twin technology in discrete manufacturing events through case study. To create digital twins for these case studies, the authors employed technologies such as Unity, Game4Automation, Siemens TIA portal, and Fishertechnik models. The case study involves the establishment of a digital twin for a production line model. This case study will serve as the foundation for developing pilot courses for Industry 4.0 education and can be further adapted to produce educational materials and technical practices related to Industry 4.0. In conclusion, the selected technologies are affordable, making the presented methodologies and educational studies accessible to a wide range of researchers and solution developers who are addressing the challenges of digital twins, with a specific focus on discrete manufacturing events.

◣ Introduction

Over the past few decades, digital manufacturing has significantly contributed to the industry by creating models and simulating the development of products and processes. This involves virtual simulations of factories, resources, labor forces, and their skills, among others [1]. The advancements in information and communication technologies (ICTs) have played a vital role in enhancing the development of manufacturing.

The development of smart products and systems, incorporating embedded systems and Internet of Things (IoT) technology, known as Cyber-Physical Systems (CPS), requires collaboration among various engineering disciplines. This collaboration involves utilizing engineering processes to define products or modules/systems and the necessary production systems for their creation [2]. Continuously evolving technologies such as wireless sensor networks, edge computing, cloud computing, fifth-generation cellular networks (5G), IoT, Big Data, and others have immense potential across industries [3]–[8]. These technologies facilitate the integration of the physical and digital worlds, which is an inevitable trend to

address the increasing complexities and demands of the market. However, the full strategic benefits of this integration have not yet been fully realized, with the focus currently on digital twins.

The concept of "product avatar" introduced by Hribernik et al. in 2006 shares similarities with the concept of a digital twin. The product avatar aimed to build an information management architecture that supports bidirectional information flow from a product-centric perspective. Research on product avatars can be found prior to 2015 [8]–[11], but it seems to have been replaced by the digital twin concept.

The credit for the digital twin concept goes to Michael Grieves and his collaboration with NASA's John Vickers. Grieves proposed the concept in a presentation on product life-cycle management in 2003. At the time, virtual product representations were relatively new and data about physical products were limited and mostly paper-based [12].

The initial definition of a digital twin is a virtual representation of a physical product that contains information about the product. It encompasses three elements: the physical product, its virtual representation, and the bidirectional data connections that transfer information and processes between the physical and virtual representations [12].

A review paper identified three potential applications for digital twins: managing the entire life cycle of a physical object, planning maintenance activities based on health conditions, and enhancing decision-making through engineering and numerical analysis [13].

The concept of digital twins in manufacturing was categorized based on data integration levels in a study by a particular author. Three subcategories were proposed to define the depth of integration of digital twins: digital model, digital shadow, and digital twin [14]. We can see all three categories in Fig. 1.
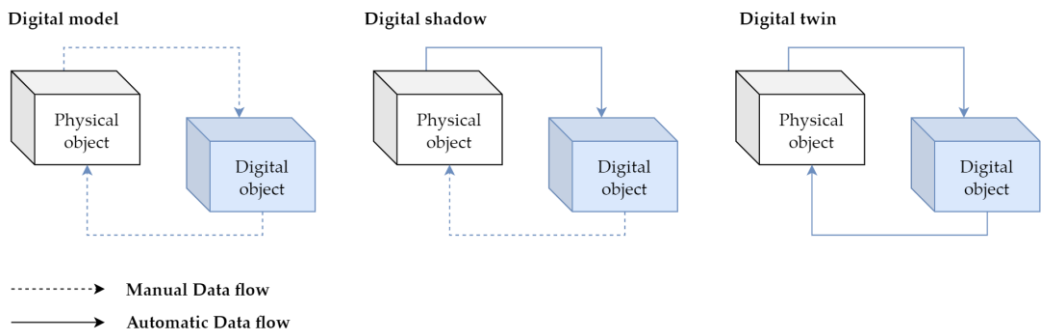

Fig. 1 The difference between digital model, digital twin, and digital shadow

A digital model is defined as a digital copy of an existing or planned physical object; there must be no automated data exchange between the physical model and digital model to define a digital model accurately [15]. Plans for constructions, product designs, and development are a few examples of digital models. The important distinctive feature is that there is no automatic data exchange between the physical system and digital model. This means that, after the digital model is created, any changes made to the physical object have no influence on the digital model.

A digital shadow is a one-way flow of information between a physical and digital object. A change in the physical object's state causes a change in the digital object, not the other way around [16].

The reference ``digital twin" is formed when data flows between an existing physical object and a digital object, and they are fully integrated in both directions. A change to the physical object triggers a change in the digital object, and vice versa [17].

These three definitions assist in identifying the typical misunderstandings found in the literature. However, a number of myths are frequent; they are not just seen in these limited scenarios. One of the misconceptions is that digital twins must be an exact 3D model of a physical object. However, some authors believe that a digital twin is just simply a 3D model [18]

Digital twin technology has found applications in a variety of industries that are undergoing digital transformation. The paper [19] identified ten major industrial sectors where digital twin has been used in their study on digital twin applications. These industries are as follows: (i) Aerospace, (ii) Manufacturing, (iii) Healthcare, (iv) Energy, (v) Automotive, (vi) Petroleum, (vii) Public sector, (viii) Mining, (ix) Marine, and (x) Agriculture. They also stated that digital twin has been used in these industries for three main purposes: simulation, monitoring, and control. However, the applications of digital twins are not limited to just these three. Design, validation, customisation, optimisation, prediction, and maintenance are all now performed with digital twins. [20] the industry which will be leading in digital twin deployment by 2021 is manufacturing (34%), followed by energy (18%). Interesting applications of DT are in papers [21], [22]. They apply DT in the context of construction industry such as On-Site Construction, Building Lifecycle Management and Infrastructure Operations, Blockchain Technology, Sustainability Assessment, or Prefabrication.

�◀ 1 Related Works

In this section we will discuss the works aimed at using digital twin mainly (but not only) in production and manufacturing processes. The research was focused on works using such technologies as digital twin, Unity, PLC, and virtual reality/augmented reality.

1.1. Robotic Application with Digital Twin or Digital Shadow

In this paper [23] a digital twin model is proposed to assist in the online/remote programming of a robotic cell. The model consists of a physical model (a FANUC robot) and a digital model (created in the Unity game engine) that replicates the physical robot. Using a digital twin setup along with virtual reality, the authors observe the trajectory replication between digital and physical robots, with a latency of approximately 40 ms and an error range of -0.3 to 0.3 degrees across the robot joint movements. The~model is deemed suitable for industrial applications, as it enables the user to program the robot's trajectory by writing and modifying code within the digital environment. The digital model is created by importing a CAD file into the Unity platform, where additional details and components are added to create a realistic simulation environment. Communication between the digital and physical models is established using the FANUC robot's API, allowing the user to control the physical robot through the digital model.

The article [24] presents a method of programming robots using virtual reality and digital twins. The virtual environment is a digital twin of a robotic station, built based on CAD models of existing station elements. The virtual reality system is used to record human movements in a virtual environment, which are then reproduced by a real robot. The method is intended to be used in situations where it is necessary for the robot to reproduce the movements of a human performing a complicated process. An example of using the method to programme a robot to clean ceramic casting moulds is presented.

The aim of the research [25] is to develop a synchronisation model of real and virtual industrial robots using the Unity game engine. This model will be tested in virtual reality and

shop floor labs. The primary outcome of the research is to enable universal control algorithms through a VR experience that can be easily modified for a wide range of industrial equipment. The digital twin of an industrial robot, Motoman GP8, was used for the experimental research and was developed using 3D modelling software. The software is designed to be easily extended to support other VR platforms and control digital twins of different industrial robots and equipment. The research also aims to improve workspace awareness of the real robot using its digital twin. Two scripts were developed for this purpose and were tested in VR and on the shop floor.

Study [26] presents the results of an experiment comparing the use of a traditional physical teach pendant and a virtual reality (VR) interface for controlling an industrial robot. In the digital twin can be operated in "coupled" and "virtual" modes. In the coupled mode, all commands are duplicated and sent to the physical robot over the local network, effectively keeping the virtual robot synchronised with its real-world counterpart. In the virtual mode, the network link between the digital twin and the real robot is disconnected. All actions happen inside the simulation only. Apart from these connection modes, the UI provides two control mechanisms for commanding robot motions. The user can either directly tele-operate the robot arm by adjusting individual joint positions, or create a multi-step, joint-space programme to be stored and executed later.

The Cyber-Physical and Intelligent Robotics Laboratory has been recreated digitally in [27], including all key elements for six-axis industrial robots to perform PTP, LIN, and CIRC motions. The human--machine interface has also been integrated, allowing users to create programmes with these motion types. The digital lab can be used for in-house training for small and medium-sized enterprises, without the need for installation, maintenance, or servicing costs. The customisability and virtual format also mean that there is no capacity limit and trainees can participate in exercises in parallel. Exercises were conducted to evaluate the programme's impact on teaching and showed that using machine units can improve teaching. The digital lab uses the Unreal Engine 4 and Blender to create a simulation of a robot control method.

1.2. Applications of Digital Twin Using VR/AR

The paper [28] discusses the use of digital twin technology in modern manufacturing enterprises. The technology allows for the digital virtualisation of different parts of the production process, which can be monitored and controlled using SCADA systems. The paper proposes the use of AVEVA Wonderware software as a tool for implementing the digital twin concept, with the goal of creating a virtual image of a real production system in the initial stage. It also discusses the importance of following the relations and rules throughout the product life cycle, and the need for sufficient depth and fineness of information about the controlled system to ensure the accuracy of the virtual image.

The article [29] discusses the use of a digital twin and virtual reality (VR) to train operators in Industry 4.0 environments. The research used a VR model developed by Game4automation, which simulates a factory setup and allows participants to control and interact with the machines. The study found that VR and the digital twin can be effective in training workers, and that it is especially helpful for older workers who may have difficulty adapting to new industrial paradigms. Feedback from participants also identified areas for improvement in the VR model, such as the user interface and task instructions.

Methodology for developing low-cost, content-rich augmented reality (AR) software using a liquid-soap synthesis process as a case study is presented in [30]. The method comprises four main modules: data creation and collection, integration, cross-platform development, and digital assets. The data creation and collection module involves creating

3D computer graphics and multiphysics computational fluid dynamics (CFD) simulations. The authors demonstrate the use of the Unity game engine to integrate these simulations into AR software and deploy the resulting tool on a mobile platform. The case study is intended to provide guidance for inexperienced developers looking to create digital teaching content. The digital tool developed in the study is available online.

The authors in [31] present a digital twin of a laser-based assembly assistance system for manual mounting tasks. The digital twin was developed using the Unity 3D game engine and implemented in augmented reality using the Microsoft HoloLens. The authors demonstrate that the digital twin can be used to support the planning, simulation, and training of employees at the shop floor. The digital twin is connected to the Mindsphere cloud and can be controlled using hand gestures and voice commands. The implementation is intended to support the use of digital twins in the planning, simulation, and training of employees in production environments.

The research in [32] is focused on digital game-based examination environment for postgraduate engineering students studying Industry 4.0 topics. The environment was developed using the Unity 3D game engine and is intended to provide a more comprehensive evaluation of students' skills and knowledge. The authors describe the use of digital game-based learning and gamification in education and present a taxonomy for learning objectives. They also explain the development of the game environment and present results from an evaluation of the environment by students. The authors conclude that the game-based examination provides a useful supplement to traditional exams and can be used to evaluate complex problem-solving and application skills.

The paper [33] discusses a novel approach to establishing a closed-loop engineering process chain for the digital factory using a combination of technologies including Game4Automation, VR, and the Internet of Things (IoT). The authors developed a VR demonstrator using the CONTACT Elements for IoT platform and a web-based production process planner and manufacturing execution system (MES) written in Java. The approach involves creating a digital twin of the production process, allowing for real-time analysis of errors or inefficiencies and simulation of changes to the production line. The demonstrator is a virtual production line and does not involve a real production line. The paper describes the architecture and functionality of the demonstrator, as well as potential applications and future developments of the approach.

The text [34] presents a case study where an AR system accesses a digital twin via web services to display real-time information to the user. The architecture of the proposed system includes five layers: devices, user interfaces, web services, queries, and data repositories. The case study involves the visualisation of an offshore oil platform process, which is a cyber-physical system (CPS) process. The AR application uses image recognition to identify equipment and display information on different virtual models, while the digital twin is updated in real-time through web services.

1.3. Applications of Digital Twin Using Fischertechnik Education Models

Articles [35], [36] present a framework for creating Intelligent Digital Twins (IDTs) in the context of the Internet of Digital Twins (IoDT) and the convergence of Industry 4.0 and Industry 5.0 paradigms. The authors propose a DT reference model aligned with Industry~4.0 and enriched with Industry 5.0 goals, and demonstrate how IDTs can be realized with the characteristics of Multi-Agent Systems (MAS). An architectural design for IDTs is presented, which coordinates marketplace-oriented production processes. The design

is tested through a prototype implementation and a proof of concept using Fischertechnik Training Factory Industry 4.0.

In this paper [37] the focus is on the creation of the Digital Shadow for the Training Factory Industry 4.0, which was developed as part of a university course. The primary goal was to investigate whether the skills and knowledge obtained during the Computer Science undergraduate program were adequate for building a functional Digital Shadow of the training factory.%MDPI: please change to e.g., Sala, R. et al. and check if it should be formatted as ref. ciattion. please provide date before 19 April 2023

This bachelor thesis project [38] analyzes the Fischertechnik 4.0 Training Factory simulation model within the context of Industry 4.0. The model is complemented with a digital twin created through Siemens Tecnomatix Plant Simulation software, and an Initial and To-Be scenario are created for analysis. The C++ software used in the model allows for the introduction of different 4.0 features and devices, but due to lack of knowledge, these aspects could not be developed further. Th Siemens Tecnomatix software is analyzed through the scenarios, and two manuals are created to make using both tools easier.

Author of [39] created a digital twin of a Fischertechnik factory simulation as part of his master's thesis at Quality Automation. The twin was developed using CAD files and Siemens program CAD/CAM system NX, and meshing was defined for each element and sensor. The virtual commissioning of the digital twin was carried out with a simulated PLC. The project included a direct comparison of the hardware model and its purely virtual twin, highlighting the possibilities of virtual commissioning and the increasing importance of simulations and virtual twins in the future.

1.4. Summary of Related Work

Based on the analysis of related works, it can be stated that most of the analysed works declared in their title or texts that they work with digital twins. Based on the elaboration and explanation of the difference between the terms digital twin and digital shadow in the Introduction section, it can be stated that most of the analysed papers proposed only digital shadow (data flow was only directed from the real system to the virtual one). We confirmed the claims in the Introduction section that digital twin is often used only as ``scientific'' marketing, a buzzword or the authors do not have enough study on the subject. The works that can certainly be considered as digital twin in the above mentioned context are the works focused on robotic workstations that have made it possible to control a real robotic system by using its digital twin.

The goal of this paper is to present a practical method for creating digital twins, both simple and complex. To achieve this, we have designed easy-to-follow educational case studies that utilize readily available tools and techniques. The primary focus of these case studies is to establish two-way communication between the actual system and its digital twin.

Our intention is to use these case studies as a starting point for developing training courses for Industry 4.0 education. Additionally, they can be further modified to create Industry 4.0 educational materials and technical resources.

◣ 2 Aim of Methodology

Before starting the actual work, we have to know what kind of tools, either hardware or software, we will need. We start with the hardware specifications of our work. The first thing we need is a device that we are going to transfer into digital form. We have used two devices. The first is an assembly line and the second is a warehouse stacker (both made by

Fischertechnik), both of which we will describe in detail in the case studies. Next, we need to control these devices. Here we have chosen a PLC device from Siemens. Specifically, the S7-1200 series with a 1215 DC/DC/DC CPU. The connection will be made via an Ethernet cable. In the software part we will first work with the TIA portal program, which will serve us for communication between the computer and the PLC device and at the same time we will program the transport line and the warehouse stacker. The digitalization itself will be carried out in the Unity game engine. Unity will serve only as an environment in which we will work. The~Game4Automation framework will play the main role in the digitalization. It is in this framework that we will try to replicate the real object as closely as possible. In Fig. 2 we can see the interconnection of the line, the software, and their mutual dependence in two-way communication.
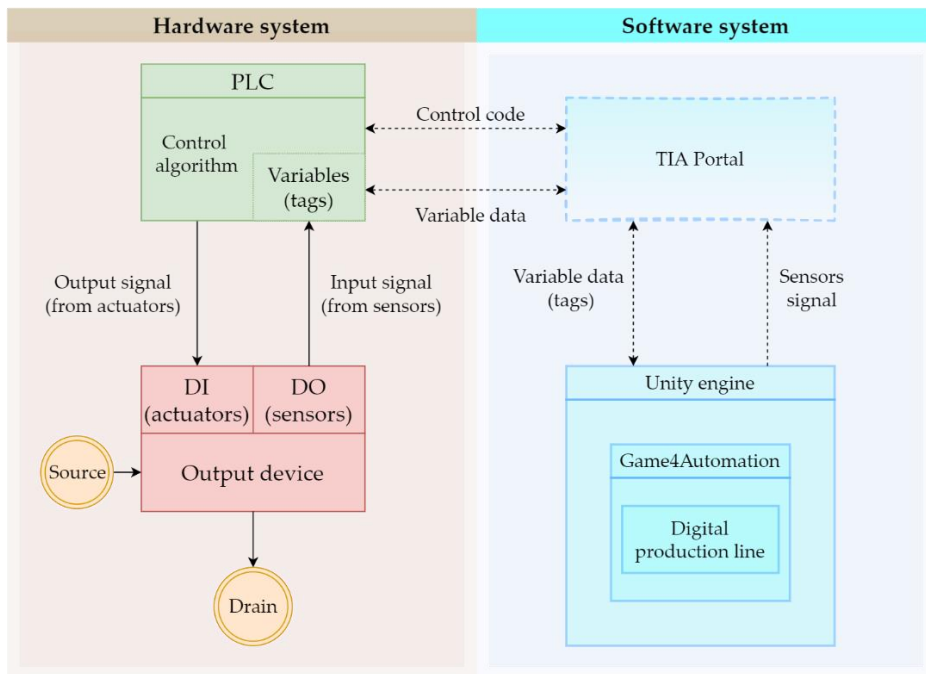
Fig. 2 Scheme of connection between hardware and software.

▶ 3 Case Study: Digital Twin of an Assembly Line

The aim of our first case study is to link the physical model of the assembly line with its digital version. At the same time, we want them to interact with each other, that is, if we perform an action on the real model, then the same action is automatically performed on the digital version and viceversa. Our discrete-event system (Fig. 2) should behave as follows:

- Two-way communication between the physical digital line will be ensured;
- The digital and physical lines will influence each other, i.e., an event executed on one will be manifested on the other.

In the next section, we will describe the tools we used in the development of our application. We tried to choose the tools in such a way that our work would be as efficient and clear as possible, especially when it comes to the software. We will go through the hardware components first and then move on to the software

Our work consists of transferring a physical object into a digital environment. The~physical object we have chosen to transfer is a model of a production line from Fishertechnik. In the Fig. 3, we can see the scheme of the assembly line. This model is a simplified version of a large production line. It consists of:

- four conveyor belts;
- five light gates;
- two sliding devices;
- two stations that simulate a drill and a milling machine.
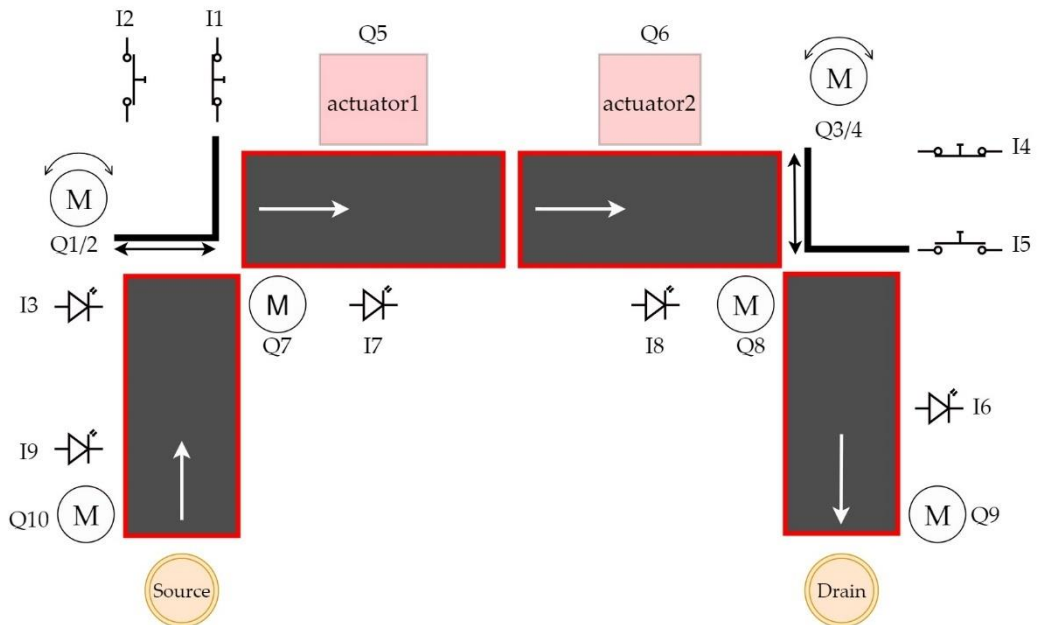
Fig. 3 Electrical scheme of assembly line

We will go through a deeper cross-section of the line in the next subsection. We can divide the line into two types of components. The first type is input devices, i.c. devices that receive stimuli from the external environment and send signals based on these stimuli. The signals are received by the second type of components the output devices. These evaluate the signal they have received and carry out their operation on that basis. The input devices include:

- a light gate;
- a slider position sensor.

-

A light gate is a photosensitive device that emits light on one side and receives it on the other. If the light beam is interrupted, the gateway sends out a signal. Another input device is a slider position sensor. This input device senses the position of the slider, which is a device that moves an object from one conveyor belt to the next, in places where the conveyor belt does not have reach. This sensor is a button that reacts when the slider is directly above it, and therefore presses it. Output devices include:

- a conveyor belt;
- a slider;
- drilling and milling station
-

Text of each chapter has font size 10 and paragraphs with line spacing single. Indentation of first line in paragraph is 1cm. Subchapters (subtitle bold, font size 10) are numbered 1.1 and 1.1.1 etc. The whole document has a Times New Roman font. Page size of printed journal is B5 (176 x 250 mm). Side borders are 2 cm inside and 1.5 cm outside. Top and bottom border 1.5 cm. Even page is on the left side, odd page on the right side of printed journal. First page of every article is on the right side.

The conveyor belt and slider start moving in a predetermined direction when a signal is received, in the case of the stations, this is only a simulation. In the Figure 4, we can see the whole production line.
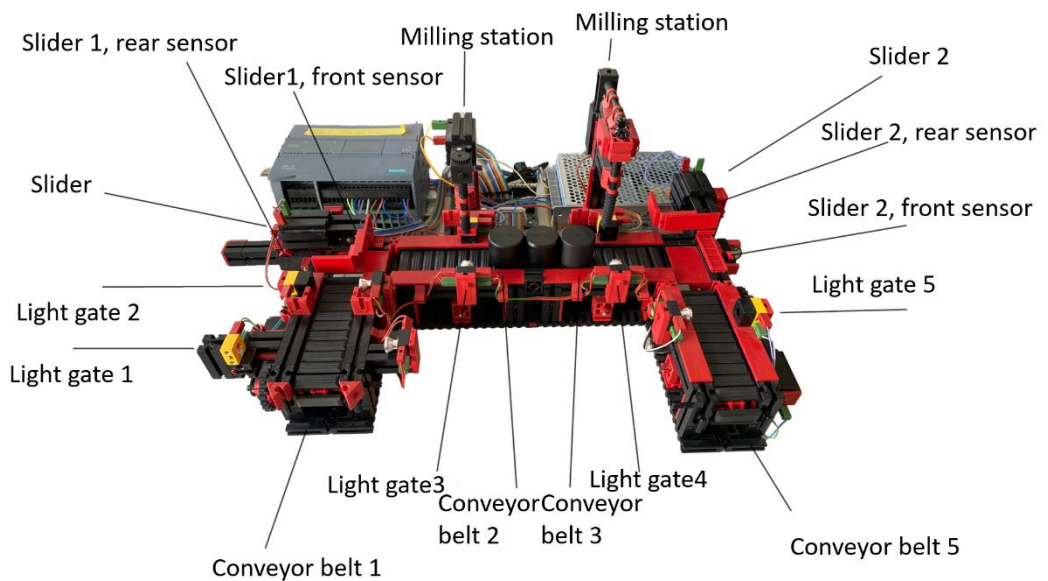

Fig. 4 Overview of the line.

◤ 4 Simulation

Once all the components of the virtual and real aspects of the task were running correctly, we
ran the simulation. If everything is wired correctly, then the twins work bilaterally, i.e., the physical twin can control the virtual twin and vice versa. In the first tests, we investigated whether the virtual twin can control the physical twin. The only difference was the speed of the goods transported, or the length of the conveyor belts. Fortunately, the framework allows changing the length of the components or accelerating the conveyor belt. In the same way, in the TIA portal environment it is possible to change the start length of the real conveyor belt. When tested in the opposite direction, no problems were encountered as each virtual component moves as long as its physical counterpart does. Something to watch out for during work is the restart of the CPU of the PLC device after each interruption of an incomplete simulation. Otherwise, the next simulation did not work properly. In the Fig. 5, we can see the finished virtual line.
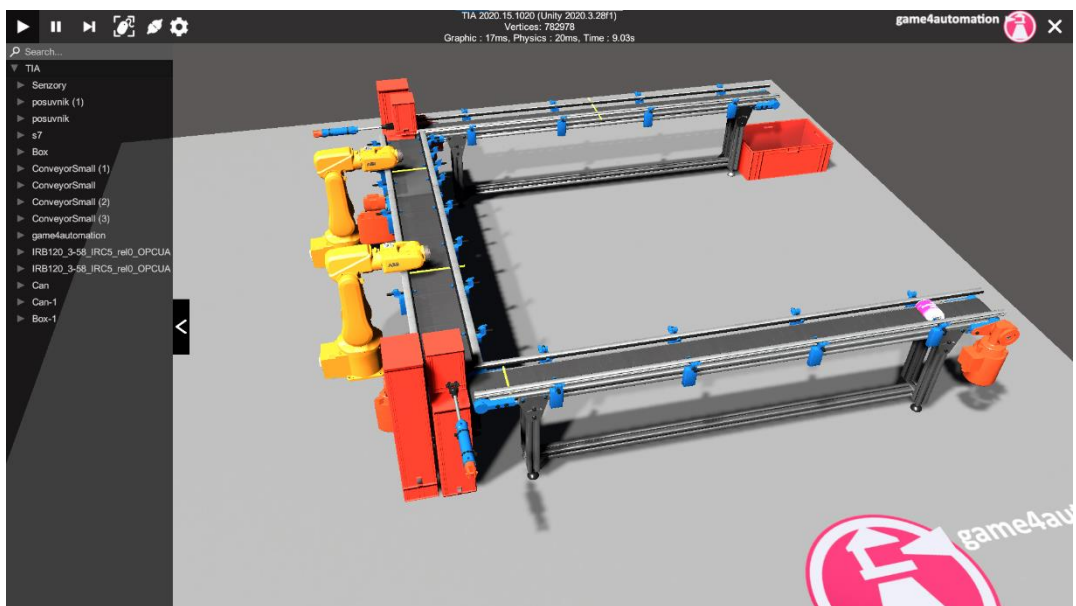

Fig. 5 Digital twin

In this state, the digital twin allows the virtual line to influence the real one and vice versa. However, this study did not address the synchronization of events in the virtual and real line. Event synchronization will be a continuation of this work, where 3D CAD models of the real line will be used. Synchronization will also allow predictive maintenance elements, as, if events in the virtual and real lines do not occur simultaneously, it will be possible to conclude that an error has occurred on the real line, for example, a slowdown of the conveyor belt due to a decrease in motor performance.

◤ Conclusion

The objective of this paper is to present a comprehensive methodology for creating digital twins, ranging from simple to more complex ones. Additionally, the paper highlights

the varying interpretations of the digital twin concept in the relevant literature and emphasizes that it is often misused as a buzzword. Through our research, we discovered that the majority of "digital twins" described in the analyzed articles did not fulfill the fundamental requirement of bidirectional data flow between the real system and its digital counterpart. In fact, a study conducted by IOT Analytics found that companies classify digital twins in up to 210 different combinations [40]. Given these observations, we decided to develop educational case studies that are simple and easily understandable, using readily available tools and techniques to create basic digital twins that satisfy the crucial condition of bidirectional communication between the real system and its digital representation. This case study will serve as the foundation for pilot courses in Industry 4.0 education and can be further adapted to develop educational materials and practical exercises for Industry 4.0.

The case study aimed to establish a connection between the physical model of an assembly line and its digital twin, enabling interaction between the two. We ensured that there was two-way communication between the physical and digital lines, so that any event executed on one line would be reflected in the other. In this paper, we describe the affordable tools we utilized for developing our application, carefully selecting them to enhance efficiency and clarity, particularly in the software aspect.

The application contributions of presented article can be summarized in the following points:

- **Educational and awareness-raising value of the article consisting in the creation of "real" digital twin**
  As the survey has shown, the vast majority of studies, despite their proclamations, do not really deal with digital twins, but only with models or shadows. We~felt it necessary to point this out and to show illustrative examples of real-life digital twins in clear and replicable cases.

- **Low-cost solution for presenting of creation of digital twin**
  Our solution offers cost-effectiveness, which is a crucial aspect compared to other solutions explored in the project. We~rely on freely or commonly available technologies.

- **Flexibility ensured by the use of Unity engine**
  It is worth highlighting that the flexibility of the solution presented in this article is due to the use of the 3D engine Unity. Unity offers a variety of tools that enabled the authors to easily create and manipulate 3D models, as well as simulate real-world interactions. The~created digital twins may not only be presented on a computer screen, but also on other platforms, such as mixed reality in Microsoft HoloLens 2.

- **Creation of new case studies for pilot projects for the creation of educational materials for the training of engineers for Industry 4.0--- pilot Engineer 4.0 programmes**

  The case studies prepared in this article, which integrate operational and information technologies, are well-suited for use in educating engineers on the digitalization of production processes. This effort will complement our previous study [41] and complement the upcoming curriculum for the Industry 4.0 pilot training programs.

In our future plans, we aim to focus on utilizing real CAD models in digital twins. Subsequently, we want to develop a methodology to verify the correct assembly of digital

twins by comparing the timestamps of events on the real and virtual lines.

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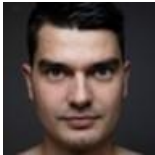
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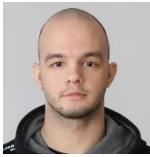
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