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Study of Robot Manipulator Control via Remote Method

Tuan Nguyen[1,*]

[1] Tien Giang University, My Tho City, Tien Giang Province, Vietnam

Abstract

INTRODUCTION: The study introduces a novel approach to the design and management of industrial robots using virtual reality technology, enabling humans to observe a wide range of robot behaviors across various environments.
OBJECTIVES: Through a simulation program, the robot's movements can be reviewed, and a program for real-world task execution can be generated. Furthermore, the research delves into the algorithm governing the interaction between the industrial robot and humans.
METHODS: The robot utilized in this research project has been meticulously refurbished and enhanced from the previously old version robotic manipulator, which lacked an electrical cabinet derived.
RESULTS: Following the mechanical and electrical upgrades, a virtual setup, incorporating a headset and two hand controllers, has been integrated into the robot's control system, enabling control via this device.
CONCLUSION: This control algorithm leverages a shared control approach and artificial potential field methods to facilitate obstacle avoidance through repulsive and attractive forces. Ultimately, the study presents experimental results using the real robot model.

Keywords: Robotics, Intelligent System, Motion Control, Complex System

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1. Introduction

Robotic systems have revolutionized the landscape of modern technology and industry, encompassing a diverse range of robotic platforms, including mobile robots [1], robot manipulators [2], and reconfigurable robots [3]. These machines are at the forefront of automation, enhancing efficiency, precision, and adaptability across various domains. In this era of rapid technological advancement, these robotic systems are not only characterized by their physical presence but also by the advanced techniques and control mechanisms that govern their operation.

One crucial aspect of modern robotics [4] is the utilization of virtual models which allows engineers and researchers to design and simulate robotic systems in a digital environment before physical implementation. This approach offers the advantage of cost-effective prototyping, enabling thorough testing and refinement of robotic functionalities without the need for extensive physical resources. It is instrumental in optimizing the performance and capabilities of robotic systems [5-8].

Motion control is another fundamental technique in the realm of robotics [9-11]. Precise control of a robot's movements, whether for navigation [12], manipulation [13], or reconfiguration [14], is essential for achieving desired outcomes. Advanced motion control algorithms and systems enable robots to execute tasks with unparalleled accuracy, speed, and dexterity, making them indispensable in industries such as manufacturing, healthcare, and logistics.

Adaptive control techniques are pivotal in ensuring that robotic systems can seamlessly adapt to dynamic and changing environments [15, 16]. These methods enable robots to continually learn and adjust their behaviour based on real-time data and sensory input. As a result, robotic

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*Corresponding author. bryan.nguyen3004@gmail.com

systems become more versatile and capable of handling unforeseen challenges, further extending their applications in unpredictable settings.

In recent years, the world of robotics has witnessed a remarkable transformation, thanks to the seamless integration of Artificial Intelligence (AI) into robotic systems [17-20]. This synergy between AI and robotics has unlocked a plethora of possibilities, revolutionizing how robots’ function, interact with their environments, and serve various industries. From manufacturing [21] and healthcare [22] to autonomous vehicles and space exploration, the applications of AI in robotics have not only expanded the capabilities of machines but have also reshaped the way we perceive and utilize them. In this exploration of the diverse applications of AI in robotics [23-25], we will delve into the innovative ways in which AI is enhancing the intelligence, adaptability, and efficiency of robots, ultimately shaping the future of automation and human-machine collaboration.

In the age of Industry 4.0, cyber-physical control plays a pivotal role in connecting robotic systems with the broader digital infrastructure [26-28]. These systems allow for real-time monitoring [29], remote operation [30], and the exchange of data between robots and other interconnected devices [31]. This integration facilitates collaborative and intelligent decision-making, ultimately enhancing the efficiency and adaptability of robotic systems across industries.

2. Prefaces

This section introduces several peripheral devices and communication protocol to connect. Additionally, the working environment is launched to embed our model.

2.1 Introduction to Virtual Reality

Virtual Reality (VR) is a groundbreaking technological marvel that has transcended the boundaries of traditional human-computer interaction, ushering us into a realm where the lines between the physical and digital worlds blur into a seamless, immersive experience [32-34]. This transformative technique has emerged as a revolutionary force in the realms of entertainment, education, healthcare, architecture, and countless other industries.

At its core, VR is a computer-generated simulation that transports users into a three-dimensional, artificial environment, often facilitated by a head-mounted display and specialized input devices [35]. The primary objective of VR is to create a sensory-rich environment that engulfs users, allowing them to interact with and explore these synthetic worlds as if they were real.

The magic of VR lies in its ability to engender a profound sense of presence. It tricks our senses, fooling our brains into believing that we are truly present in a virtual environment [36]. Visual, auditory, and sometimes even tactile stimuli converge to create an immersive experience that is unlike any other. As a result, VR has become a powerful tool for simulating situations, training individuals, and fostering experiences that were previously unattainable.

In Fig. 1, VR glasses, also known as VR headsets or VR goggles, come in various forms and designs, but they generally share a common structure and components that enable immersive VR experiences. The typical structure of VR glasses consists of

- *Head-Mounted Display (HMD):* The core component of VR glasses is the head-mounted display, which is worn on the user's head. This display is responsible for showing the virtual environment to the user. It typically consists of two screens, one for each eye, to create a stereoscopic 3D effect
- *Optics*: VR glasses have a series of lenses or optical elements that sit between the screens and the user's eyes. These lenses are crucial for adjusting the focus and magnification of the displayed images, ensuring that the virtual world appears clear and immersive
- *Straps and Adjustments*: To keep the VR headset securely in place, it is equipped with adjustable straps that go around the user's head. These straps are often padded for comfort and can be tightened or loosened to fit different head sizes. There may also be additional adjustments to fine-tune the position and angle of the display for optimal viewing
- *Sensors and Tracking Technology*: VR glasses incorporate various sensors, such as accelerometers, gyroscopes, and magnetometers, to track the user's head movements. This tracking data is essential for updating the view in real-time as the user looks around the virtual environment, enhancing the sense of immersion. Some advanced VR systems also use external sensors or cameras for room-scale tracking, allowing users to move around in physical space.

Figure 1. Meta Quest 2 VR headset.

2.2. Working platform

Unity is a powerful and versatile game development platform that has emerged as a driving force behind some of the most captivating and interactive digital experiences of our time. It stands at the forefront of the technology industry, enabling developers to create immersive 2D, 3D, augmented reality (AR), and VR applications across multiple platforms. Unity's impact reaches far beyond gaming, extending into fields such as education, architecture, healthcare, and entertainment, where its capabilities have been harnessed to craft innovative solutions and captivating content.

Besides, unity is a cross-platform game engine and development environment, renowned for its ease of use and accessibility. It empowers creators, from indie developers to large studios, to bring their ideas to life, blurring the lines between the real and digital worlds. Unity's robust ecosystem provides a comprehensive suite of tools, including a powerful visual editor, scripting capabilities, and a vast library of assets and plugins, all designed to streamline the development process

2.3 Camera setup

Setting up a RealSense camera involves a few steps to ensure that it is connected correctly and that users have the necessary software drivers and applications installed.

- **Connect the Camera**: Plug the RealSense camera into an available USB port on your computer. Ensure that it is securely connected
- **Check Camera Compatibility**: Ensure that the RealSense camera is compatible with the version of the SDK (Software Development Kit) installed in computer

Both 2D and depth images captured by Realsense cameras have a resolution of 640x480 pixels, with each pixel in 2D photos corresponding to a depth camera point. When obtaining the pixel coordinates of a point in an RGB image, it is possible to recover the x, y, and z values of that point in camera coordinates. This is because the true coordinate system in Realsense is defined to align with the colour space in the camera coordinate system.

Figure 2. Description of the proposed design.

3. The Proposed Design

3.1 Robot model

Unity3D does support the creation of 3D models within the project. However, designing complex-looking models may be challenging using Unity3D's fewer professional tools, as Unity3D is primarily tailored for game development.

Therefore, it is most common to design a mechanical model in other professional software such as AutoCAD, SolidWorks, Fusion, and similar tools. However, it's not possible to directly import 3D files into Unity3D because it only supports specific formats. Thus, this thesis focuses on converting the file formats into ones compatible with Unity. This conversion process involves using a middleware to alter the format without modifying the original data of the files. In this case, Blender is employed to address this issue as Fig. 2.

3.2 Programming procedure

Working within the virtual environment involves a working table (initially 500mm in length and 300mm in width before scaling) and a leader cube. The user guides the cube to desired positions, and the robot arm follows the cube's path. In this scenario, it's necessary to transform the coordinates of the cube into the robot's coordinate system, as the robot is controlled using the inverse kinematic method. As shown in Fig. 3, it is important to note that Unity employs a left-handed, Y-Up coordinate system

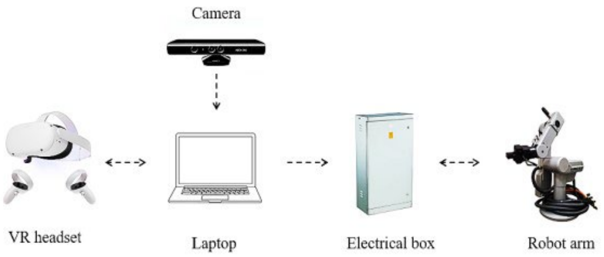


Figure 3. Description of inter-connection for data exchange.

Because of the different robot model, the DH table is based on the five axes robot model as Fig. 4, even though the general placement of coordinates is the same as the common robotic platform. The components are organized in a hierarchical order so that the rotation angles of each link correspond to the rotational movement of each part. Due to the automatic coordinate placements, each part must be aligned with a virtual coordinate system that coincides with the rotation axis. This ensures that the entire part rotates as required

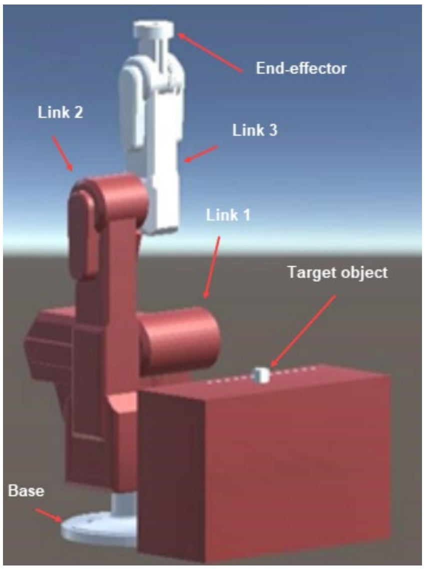


Figure 4. Description of the proposed design for robot model.

3.3 Camera calibration

It is necessary to acquire obstacle data from OpenCV in addition to the Kinect library. OpenCV (Open-Source Computer Vision Library) is a collection of programming functions primarily designed for real-time computer vision applications. The primary programming language used in this thesis is C#. To transmit the data to Unity, socket communication based on the local host is employed.

3.4 Data exchange

The computer-based sampling time refers to the time required to generate new control data for the robot after collecting data from VR and processing it according to the algorithm, without considering the camera factor. This time can be estimated to be less than 3ms. Therefore, the condition for selecting the sampling time is as follows: $T_{samp} > T_{samp}$, where the computer program's time, $T_{computer}$, is set to 500ms.

However, once the real robot's pose is set, it becomes challenging to predict the precise time it will take for the robot to transition to its next set of movements. This uncertainty arises because the drivers must generate new control signals for the motors only after the previous movements have been completed. In some cases, this process might go smoothly, but there is a possibility of encountering errors that render the drivers unresponsive. Given these uncertainties, the interval for receiving new signals from the drivers is determined in a somewhat randomized manner, typically set at 3 seconds. This selection is made with a specific condition in mind: that the displacement of the end-effector remains relatively short during each sampling period.

3.4 The proposed control scheme

The artificial potential field comprises two primary components: repulsion potential energy and attractive potential energy. As a general principle of this algorithm, the robot is steered in a direction that reduces the total potential energy, thereby moving toward the target while concurrently navigating away from obstacles.

Repulsion potential energy involves the exertion of a repulsive force on the robot arm by an obstacle at a defined distance. This implies that the force's direction will likely be opposite to the vector pointing from the robot arm to the obstacle, as depicted in Fig. 5. Consequently, this mechanism enables the robot to effectively evade obstacles. In this thesis, such forces are applied individually to each joint to ensure obstacle avoidance for the entire manipulator. The calculation for the repulsion potential energy of each joint is as follows

$$Uir = \begin{cases} \frac{1}{2} Kr \left(\frac{1}{di} - \frac{1}{dsafe}\right)^2, di \leq dsafe \\ 0, di > dsafe \end{cases} \tag{1}$$

i: the order of each joint. i=3 for this investigation
Kr: repulsion gain
di: distance between joint to obstacles.
dsafe: safe distance which allow robot work in normal mode

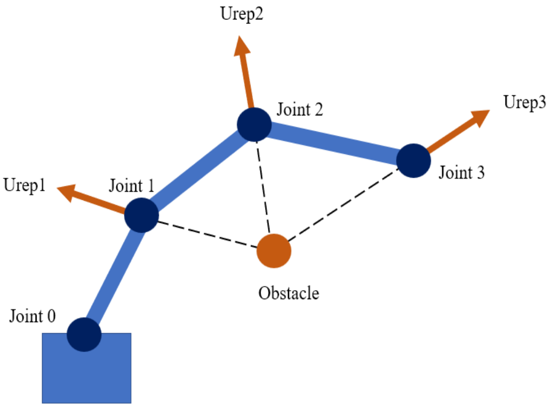
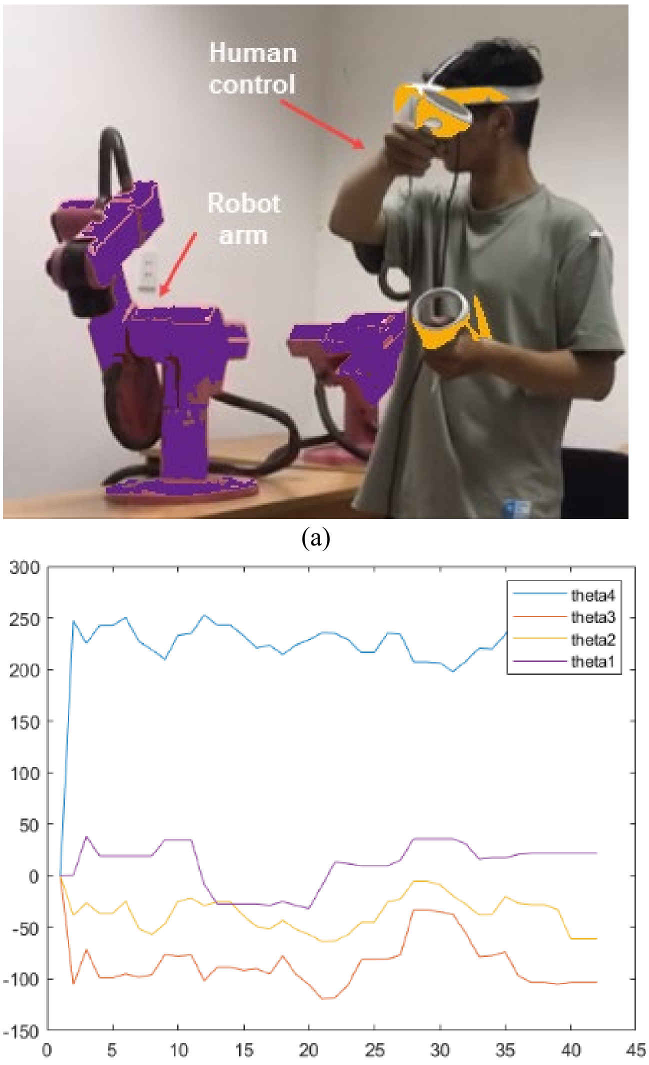


Figure 5. Illustration of the repulsion forces in the proposed model.

4. Experiment of Study

In this section, real-world validations of the proposed method were conducted to evaluate its feasibility and effectiveness. The system comprises a robotic platform, an electric cabinet, a motion controller, virtual glass, and a teach pendant. The overall setup is depicted in Fig. 6a, while an operator primarily interacts with the proposed system. During robot manipulation, data is collected from various sensors, as shown in Fig. 6b, and transmitted to the host computer



(a)

(b)

Figure 6. Result of the proposed approach, (a) practical implementation and (b) rotational angles of robot platform.

In our tests, this system demonstrated effective performance in various real-world scenarios. It exhibited flexibility in responding to human movements and vibrations. Given the continuous and intricate nature of human motion, it is imperative to implement data filtering to attain precise estimations. Moreover, this dataset can be leveraged for predicting human actions or supporting human-robot interactions when necessary. Comparing to previous works [37, 38], our study gained many benefits owing to the powerful performance of mathematical model, vivid illustration, and easy interface. It is expected that this approach could be implemented some distinguished schemes and computations.

5. Conclusion

This study introduces a novel approach for controlling a robotic platform within a virtual environment. The objectives of this proposed system encompass three key aspects: (1) establishing a robust hardware connection to facilitate seamless and continuous data transmission, (2) realizing the concept of a cyber-physical system within the realm of robot manipulation, and (3) enhancing human-robot interaction. Within this design framework, several components must be described and installed to meet specific requirements. The proposed method presents a mechanism for data flow exchange and an overall scheme for manipulation. To illustrate the effectiveness and feasibility of this approach, a real-world example of driving the robotic system was implemented. In the future, deploying modern hardware platforms will be essential to achieve high-performance results. Additionally, considering enhanced schemes such as machine learning or human-in-the-loop interactions could further improve the system's behaviour.

References

[1] Ortigoza, R. S., Marcelino-Aranda, M., Ortigoza, G. S., Guzman, V. M. H., Molina-Vilchis, M. A., Saldana-Gonzalez, G., ... & Olguin-Carbajal, M. (2012). Wheeled mobile robots: a review. *IEEE Latin America Transactions*, *10*(6), 2209-2217.

[2] Zhang, D., & Wei, B. (2017). A review on model reference adaptive control of robotic manipulators. *Annual Reviews in Control*, *43*, 188-198.

[3] Ngo, H. Q. T., Cao Tri, H., Tu, N. T., Bao, D. N. T., Anh Duy, P. L., Phat, K. M., ... & Tin, N. T. (2022). Design of reconfigurable mechanism for underactuated robot in the grounded applications. *Cogent Engineering*, *9*(1), 2095882.

[4] García, P. L., Crispel, S., Saerens, E., Verstraten, T., & Lefeber, D. (2020). Compact gearboxes for modern robotics: A review. *Frontiers in Robotics and AI*, *7*, 103.

[5] Stan, L., Nicolescu, A. F., Pupăză, C., & Jiga, G. (2023). Digital Twin and web services for robotic deburring in intelligent manufacturing. *Journal of Intelligent Manufacturing*, *34*(6), 2765-2781.

[6] Li, C., Fu, L., & Wang, L. (2018, June). Innovate engineering education by using virtual laboratory platform based industrial robot. In *2018 Chinese Control and Decision Conference (CCDC)* (pp. 3467-3472). IEEE.

[7] Shi, Y., Wang, T., Yu, J., Xiao, S., Xiong, L., & Yang, L. (2023, January). Virtual Potential Field-Based Motion Planning for Human-Robot Collaboration via Kinesthetically Guided Teleoperation. In *2023 7th International Conference on Robotics, Control and Automation (ICRCA)* (pp. 37-44). IEEE.

[8] Pérez, L., Diez, E., Usamentiaga, R., & García, D. F. (2019). Industrial robot control and operator training using virtual reality interfaces. *Computers in Industry*, *109*, 114-120.

[9] Yu, J., Wang, M., Dong, H., Zhang, Y., & Wu, Z. (2018). Motion control and motion coordination of bionic robotic fish: A review. *Journal of Bionic Engineering*, *15*, 579-598.

[10] Ngo, H. Q. T., & Nguyen, M. H. (2022). Enhancement of the Tracking Performance for Robot Manipulator by Using the Feed-forward Scheme and Reasonable Switching Mechanism. *Journal of Robotics and Control (JRC)*, *3*(3), 328-337.

[11] Al Mamun, M. A., Nasir, M. T., & Khayyat, A. (2018). Embedded system for motion control of an omnidirectional mobile robot. *IEEE Access*, *6*, 6722-6739.

[12] Nguyen, T. P., Nguyen, H., & Ngo, H. Q. T. (2023). Visual application of navigation framework in cyber-physical system for mobile robot to prevent disease. *International Journal of Advanced Robotic Systems*, *20*(2), 17298806231162202.

[13] Beltran-Hernandez, C. C., Petit, D., Ramirez-Alpizar, I. G., Nishi, T., Kikuchi, S., Matsubara, T., & Harada, K. (2020). Learning force control for contact-rich manipulation tasks with rigid position-controlled robots. *IEEE Robotics and Automation Letters*, *5*(4), 5709-5716.

[14] Seo, J., Paik, J., & Yim, M. (2019). Modular reconfigurable robotics. *Annual Review of Control, Robotics, and Autonomous Systems*, *2*, 63-88.

[15] Wang, H. (2016). Adaptive control of robot manipulators with uncertain kinematics and dynamics. *IEEE Transactions on Automatic Control*, *62*(2), 948-954.

[16] Rajasekaran, V., Aranda, J., Casals, A., & Pons, J. L. (2015). An adaptive control strategy for postural stability using a wearable robot. *Robotics and Autonomous Systems*, *73*, 16-23.

[17] Vrontis, D., Christofi, M., Pereira, V., Tarba, S., Makrides, A., & Trichina, E. (2022). Artificial intelligence, robotics, advanced technologies and human resource management: a systematic review. *The International Journal of Human Resource Management*, *33*(6), 1237-1266.

[18] Kunze, L., Hawes, N., Duckett, T., Hanheide, M., & Krajník, T. (2018). Artificial intelligence for long-term robot autonomy: A survey. *IEEE Robotics and Automation Letters*, *3*(4), 4023-4030.

[19] Phan, L. A. D., & Ngo, H. Q. T. (2023). Application of the Artificial Intelligence Technique to Recognize and Analyze from the Image Data. In *Deep Learning and Other Soft Computing Techniques: Biomedical and Related Applications* (pp. 77-89). Cham: Springer Nature Switzerland.

[20] Raj, M., & Seamans, R. (2019). Primer on artificial intelligence and robotics. *Journal of Organization Design*, *8*, 1-14.

[21] Arinez, J. F., Chang, Q., Gao, R. X., Xu, C., & Zhang, J. (2020). Artificial intelligence in advanced manufacturing: Current status and future outlook. *Journal of Manufacturing Science and Engineering*, *142*(11), 110804.

[22] Ngo, H. Q. T., Le, V. N., Thien, V. D. N., Nguyen, T. P., & Nguyen, H. (2020). Develop the socially human-aware navigation system using dynamic window approach and optimize cost function for autonomous medical robot. *Advances in Mechanical Engineering*, *12*(12), 1687814020979430.

[23] Soori, M., Arezoo, B., & Dastres, R. (2023). Artificial intelligence, machine learning and deep learning in advanced robotics, A review. *Cognitive Robotics*.

[24] Nguyen, T. P., Nguyen, H., & Ngo, H. Q. T. (2023). Developing and Evaluating the Context-Aware Performance of Synchronization Control in the Real-Time Network Protocol for the Connected Vehicle. *Mobile Networks and Applications*, 1-22.

[25] Wang, L. (2019). From intelligence science to intelligent manufacturing. *Engineering*, *5*(4), 615-618.

[26] Nikolakis, N., Maratos, V., & Makris, S. (2019). A cyber physical system (CPS) approach for safe human-robot collaboration in a shared workplace. *Robotics and Computer-Integrated Manufacturing*, *56*, 233-243.

[27] Ngo, H. Q. T., Nguyen, H., & Nguyen, T. P. (2023). Fenceless Collision free Avoidance Driven by Visual Computation for an Intelligent Cyber Physical System Employing Both Single and Double S Trajectory. *IEEE Transactions on Consumer Electronics*.

[28] Liu, H., & Wang, L. (2020). Remote human–robot collaboration: A cyber–physical system application for hazard manufacturing environment. *Journal of manufacturing systems*, *54*, 24-34.

[29] Zhou, J., Sun, J., Zhang, M., & Ma, Y. (2020). Dependable scheduling for real-time workflows on cyber–physical cloud systems. *IEEE Transactions on Industrial Informatics*, *17*(11), 7820-7829.

[30] Lee, J., & Kundu, P. (2022). Integrated cyber-physical systems and industrial metaverse for remote manufacturing. *Manufacturing Letters*, *34*, 12-15.

[31] Nguyen, T. P., Nguyen, H., & Thinh Ngo, H. Q. (2022). Planning the Emergency Collision Avoidance Strategy Based on Personal Zones for Safe Human-Machine Interaction in Smart Cyber-Physical System. *Complexity*, *2022*.

[32] Anthes, C., García-Hernández, R. J., Wiedemann, M., & Kranzlmüller, D. (2016, March). State of the art of virtual reality technology. In *2016 IEEE aerospace conference* (pp. 1-19). IEEE.

[33] Abich IV, J., Parker, J., Murphy, J. S., & Eudy, M. (2021). A review of the evidence for training effectiveness with virtual reality technology. *Virtual Reality*, *25*(4), 919-933.

[34] Morimoto, T., Kobayashi, T., Hirata, H., Otani, K., Sugimoto, M., Tsukamoto, M., ... & Mawatari, M. (2022). XR (extended reality: virtual reality, augmented reality, mixed reality) technology in spine medicine: status quo and quo vadis. *Journal of Clinical Medicine*, *11*(2), 470.

[35] Kohli, V., Tripathi, U., Chamola, V., Rout, B. K., & Kanhere, S. S. (2022). A review on Virtual Reality and Augmented Reality use-cases of Brain Computer Interface based applications for smart cities. *Microprocessors and Microsystems*, *88*, 104392.

[36] Tang, Y. M., & Ho, H. L. (2020). 3D modeling and computer graphics in virtual reality. In *mixed reality and three-dimensional computer graphics*. IntechOpen.

[37] Pérez, L., Diez, E., Usamentiaga, R., & García, D. F. (2019). Industrial robot control and operator training using virtual reality interfaces. *Computers in Industry*, *109*, 114-120.

[38] Malik, A. A., Masood, T., & Bilberg, A. (2020). Virtual reality in manufacturing: immersive and collaborative artificial-reality in design of human-robot workspace. *International Journal of Computer Integrated Manufacturing*, *33*(1), 22-37.