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Triwiyanto Triwiyanto
Achmad Rizal
Wahyu Caesarendra *Editors*

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Preface

4th ICEBEHI-2023, the 4th International Conference on Electronics, Biomedical Engineering, and Health Informatics, takes place during October 4–5, 2023 on virtual platforms (Zoom app). The conference was organized by the Department of Medical Electronics Technology, Health Polytechnic Ministry of Health Surabaya (Poltekkes Kemenkes Surabaya), Surabaya, Indonesia, and Co-organized by Telkom University, Bandung, Indonesia, University College TATI, Malaysia, Universitas Trisakti, Indonesia, and Walchand Institute of Technology, India. With the aim of bringing together as a family all leading scientists, academicians, educationists, young scientists, research scholars, and students to present, discuss, and exchange their experiences, Innovation ideas, and recent development in the field of electronics, biomedical engineering, and health informatics.

The ICEBEHI-2023 conference was held online through Zoom application. More than 100 participants (presenter and non-presenter) attended the conference, they were from Vietnam, Malaysia, Russia, Brunei Darussalam, Azerbaijan, China, South Korea, Australia, Poland, Libya, India, and Indonesia. The scientific program of this conference included many topics related to electronics and biomedical engineering as well as those in related fields. In this conference, three distinguished keynote speakers and one invited speaker had delivered their research works in the area of Biomedical Engineering. Each keynote speech lasted 50 minutes.

ICEBEHI-2023 Conference collects the latest research results and applications on electronics, biomedical engineering, and health informatics. It includes a selection of 46 papers from 93 papers submitted to the conference from universities all over the world. All of the accepted papers were subjected to strict peer-reviewing by 2–3 expert referees. All articles have gone through a plagiarism check. The papers have been selected for this volume because of quality and relevance to the conference.

We are very grateful to the committee which contributed to the success of this conference. Also, we are thankful to the authors who submitted the papers, it was the quality of their presentations and communication with the other participants that really made this web conference fruitful. Last but not least, we are thankful to the Lecture Note in Electrical Engineering (Springer) Publishing for their support, it was not only the support but also an inspiration for organizers. We hope this conference can be held every year to make it an ideal platform for people to share views and experiences in electronics, biomedical engineering, health informatics, and related areas. We are expecting you and more experts and scholars around the globe to join this international event next year.

Surabaya, Indonesia Dr. Triwiyanto Triwiyanto
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by Henry Candra FTI

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The Application of Virtual Reality Using Kinect Sensor in Biomedical and Healthcare Environment: A Review

Henry Candra, Umi Yuniati, and Rifai Chai

Abstract Virtual Reality (VR) and the Kinect sensor, as promising tools in biomedical research, offers diverse applications in medical education, rehabilitation, diagnostics, and health research. The problem statement highlights the demand for innovative solutions and introduces VR and Kinect as potential transformative technologies. This review analyzes the importance of these technologies, their contributions, and future potential. It stands out by evaluating various Kinect-based systems in medical settings. By highlighting distinct features, advancements, and limitations, it provides guidance for future research. Relevant literature was gathered from databases such as Google Scholar, IEEE Xplore, and PubMed. The results showcase a wide range of applications, including patient autonomy, stroke rehabilitation, diagnostics, and monitoring. Despite challenges in accurate movement tracking, integration into clinical settings, and limited generalizability of findings due to small sample sizes, VR and Kinect show potential for revolutionizing healthcare delivery and improving patient outcomes. Their adaptability, affordability, and immersive nature of these technologies offer promising avenues for personalized interventions, remote healthcare, training, and enhanced patient engagement. As these technologies evolve, continued research and development are crucial to optimize their impact in shaping the future of healthcare.

Keywords Virtual reality · Kinect sensor · Biomedical fields · Healthcare solutions

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1 Introduction

Virtual reality (VR) has become a promising biomedical research tool, showing great potential in recent years. Its applications span various areas within the field, such as in medical educational, surgical simulation, and therapy [1]. For instance, VR instruments like headsets and motion controls have been employed in rehabilitation therapy to aid patients recovering from stroke [2] and brain injuries. By allowing individuals to practice motor skills in a secure virtual environment, these systems contribute to accelerating the recovery process and improve motor function [3].

In addition to rehabilitation, VR finds utility in medical education. Medical and healthcare students can utilize VR headsets and other resources to simulate medical procedures and explore human anatomy virtually, such as surgical simulation [4]. This immersive approach enhances their training experience, providing a more realistic environment to develop their medical skills [5]. Furthermore, VR is valuable in medical diagnostics, enabling doctors to make more precise diagnoses by using data from medical imaging [3]. The mechanisms allow doctors to identify health problems and develop more effective treatment plans quickly.

Moreover, VR is vital in health research, particularly in psychology, neurology, and psychiatry. Researchers can create controlled environments using VR headsets and observe participants' responses and behaviors in simulated situations. These experiments facilitate the exploration and development of novel interventions for various health problems.

The Kinect sensor technology, as a virtual reality device, stands out for its affordability, user-friendliness, and potential for advancement in medical and healthcare applications [6] in recent years. The advent of the Kinect and associated libraries has led to increased research interest on practical applications [7].

This review aims to comprehensively analyze the role of these technologies, the contributions they make to healthcare, and their implications for the future. This study distinguishes itself by conducting a systematic comparison and analysis of a diverse range of Kinect-based systems applied to biomedical and healthcare environment. By highlighting the unique features, innovations, and limitations of each approach, this review provides a comprehensive overview that can guide future research and development efforts.

2 Virtual Reality (VR) and Kinect Sensor

2.1 Definition and History of VR

Virtual reality is a computer program that enables individuals to connect and engage with computer-generated surroundings, replicating real-life experiences and involving all the senses. It offers interactive and immersive experiences, commonly known as the two I's. However, there exists a lesser known third aspect of virtual reality. Virtual reality possesses applications that provide practical solutions to real-world challenges beyond being a medium or advanced user interface. Virtual reality professionals develop these applications. The effectiveness of a particular application, or how well a simulation performs, heavily relies on the human imagination—the third "I" of virtual reality. Thus, virtual reality represents immersion, interaction, and imagination. Vision in virtual reality also pertains to the mind's ability to perceive things that do not exist [8].

Virtual reality has a history spanning over 40 years. In 1962, Morton Heilig patented the Sensorama Simulator. This first virtual reality video arcade offered a multi-sensory experience with 3D video, motion, colour, sound, aromas, wind effects, and a vibrating seat. Sutherland's work in 1966 introduced the concept of head-mounted displays (HMDs) and the use of computer-generated scenes instead of analog images. Brooks and his colleagues later simulated force fields and collision forces using robotic arms, paving the way for today's haptic technology. The military's interest in digital simulators drove classified research, and NASA developed the Virtual Visual Environment Display (VIVED) in 1981, influencing modern VR headsets. NASA's integration of computers and trackers created the first VR system, while Scott Fisher's contributions enhanced interaction with sensing gloves and virtual sound sources. These advancements spurred international conferences and firmly established virtual reality in the scientific and engineering communities.

VPL Inc., led by Jaron Lanier, emerged as the first to sell VR products. They introduced the groundbreaking DataGlove, which revolutionized computer interaction with its fiber-optic sensors enabling gesture-based input in 1987. However, the DataGlove was expensive and lacked tactile feedback. In 1989, Nintendo released the more affordable PowerGlove, although its downfall was the limited game support. VPL also introduced the EyePhones, commercial head-mounted displays, in the late 1980s, but they suffered from low resolution and high prices. Integration challenges persisted, prompting VPL to develop the turnkey VR system, RB2 Model 2. Division Ltd. introduced the integrated VR workstation, Vision, and the consequential Provision 100 in 1992. Sense8 Co.'s WorldToolKit and Dimension International's Virtual Reality Toolkit (VRT3) addressed the software development challenges in the 1990s.

Early virtual reality (VR) hardware faced several challenges in the 1990s. The VR market was small, with most pioneering companies lacking resources for product improvements and relying on private capital. Unrealistic public expectations and funding limitations led to the disappearance of many VR companies. However, a small group of scientists continued VR research. Significant advancements in PC hardware, such as faster CPUs and graphics accelerators, facilitated VR's rebirth in the late 1990s. The performance of PC graphics matched or exceeded high-end SGI graphics supercomputers by 2001, thanks to rapid technological advances. Additionally, breakthroughs in VR interfaces, including lightweight and higher-resolution LCD-based HMDs and the introduction of large-volume displays, further contributed to the growth of the VR market.

2.2 VR Technology and Its Components

Virtual reality (VR) systems have five main components: VR Engine, Input/Output Devices, Software and Database, User, and Task [8]. The block diagram in Fig. 1 illustrated the architecture of VR [9]. VR Engine is the core software framework that powers VR experiences by rendering virtual environments, managing physics simulations, integrating tracking data, and enabling real-time interactivity. Input devices capture user interactions and movements, while output devices provide sensory feedback. Examples include motion controllers, data gloves, positional trackers, head-mounted displays (HMDs), audio systems, and haptic feedback devices. Software and databases are essential for developing, customizing, and deploying VR applications. The developments include content creation tools, simulation software, user interface systems, and APIs. A database or content management system stores virtual assets like 3D models, textures, sounds, and user data. The user is the participant who engages with the VR system through input and output devices, experiencing a sense of presence and interaction. User comfort, safety, and overall experience are crucial considerations. The task is the purpose and objectives of using VR, defining specific activities, simulations, or experiences the system aims to provide. VR applications span various domains, such as gaming, entertainment, education, training, and scientific research. The task component guides the design and development of the virtual environment and user interactions to support the intended use case.

Through the seamless integration of these five components, virtual reality systems generate attractive and interactive encounters, transporting users to simulated realms where they can explore, interact, and engage in manners surpassing the physical world's limitations.

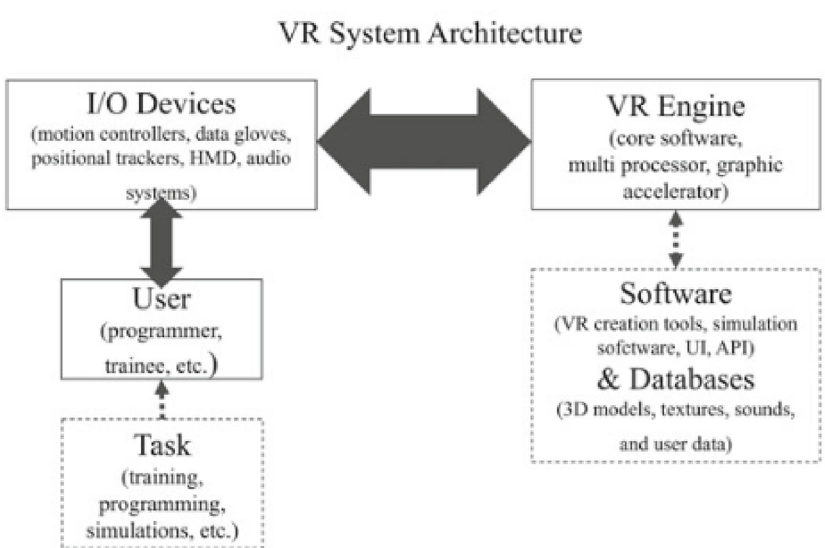

Fig. 1 The five components of a VR system

2.3 The Role of Kinect Sensor in VR

The Kinect sensor is a motion-sensing input device initially developed by Microsoft for gaming on the Xbox console. Kinect sensor V1, released in 2010, utilized infrared depth sensing, an RGB camera, and microphones to capture motion and audio data [10]. It allowed users to control games and menus through body movements and voice commands. Kinect Sensor V2, introduced in 2014, offers improved depth and image sensors, which may enhance its accuracy in assessing postural control and balance impairments. Both versions employed skeletal tracking technology, enabling immersive interactions through gestures, voice, and facial recognition. However, Kinect V2 provided better performance and advanced features, making it the preferred choice for users and developers in virtual reality, gaming, and other applications [11].

While it was primarily designed for gaming, the Kinect sensor has also found applications in VR systems. Known as a depth camera, it revolutionizes robot perception worldwide, replacing traditional cameras and range finders. Its depth-sensing capabilities enable detailed environment understanding and map generation, setting it apart from other vision systems. The Kinect sensor's ability to capture high-quality images and depth information about the environment at an affordable price has led to its widespread adoption in numerous research projects [12].

Research by El-laithy et al. aims to integrate the Kinect sensor into an autonomous ground vehicle, the Unmanned Utility Robotic Ground Vehicle (UURGV), to enhance its capabilities. The UURGV can autonomously cut grass and navigate outdoor areas using a laser scanner sensor and GPS. However, GPS navigation is ineffective indoors or near solid concrete structures. They propose integrating the Kinect sensor with other sensors, such as an inertial measurement unit (IMU), to optimize indoor navigation. By utilizing the Kinect's depth camera, the robot can detect approximate distances to objects and navigate around them while also gaining 3D perception [12].

Correa et al. project introduces a perception system for autonomous navigation of mobile surveillance robots in indoor environments. The method comprises two components: a reactive navigation system that uses the Kinect distance sensor to avoid obstacles and an artificial neural network (ANN) trained on Kinect data to identify various environment configurations. By combining reactive and deliberative behaviours, the robot can navigate using a topological map represented as a graph. The system shows promising outcomes regarding autonomous mobile robot navigation, including the ability to operate in dark environments, and its effectiveness was verified using a Pioneer P3-AT robot [13].

The paper by Eric and Jang focuses on using the Kinect depth sensor, a low-cost range sensor, to detect objects and measure their distance, providing an affordable and reliable option for computer vision. The results demonstrate that the Kinect sensor and segmentation techniques can effectively detect objects and accurately measure their distance. This research makes it suitable for obstacle avoidance and other applications that require a vision sensor, not only for unmanned vehicles but also for manned vehicles to alert drivers. Computer vision plays a crucial role in vehicles without human intervention [14].

A common use of the Kinect sensor in VR is full-body tracking. It allows users to see their body movements replicated in the virtual world, enhancing the sense of presence and embodiment. The method can be precious in VR applications focused on physical training, rehabilitation, or social interactions. Additionally, the Kinect sensor's microphone array enables voice recognition and voice commands, allowing users to interact with the VR environment using speech. The system can enhance the usability and hands-free nature of VR experiences.

Clark et al. conducted a study to evaluate and compare the accuracy and consistency of kinematic data collected from a marker-based 3D motion analysis system and the Kinect Sensor V2 across different static and dynamic balance evaluations. The results showed excellent concurrent validity for trunk angle data in active tasks and anterior–posterior range and path length in static balance tasks, indicating the potential of the Kinect Sensor V2 as a reliable and valid tool for assessing specific aspects of balance performance [15].

3 Applications of VR and Kinect Sensor in Biomedical and Health Fields

Virtual reality (VR) has shown significant potential in the biomedical field, offering a range of applications. In these domains, using virtual reality (VR) involves the implementation of computer-generated environments and simulations that deeply engage individuals, aiming to improve medical research, education, diagnostics, healthcare services, treatment, and rehabilitation. By leveraging VR technology, biomedical professionals can explore and interact with virtual representations of anatomical structures, physiological processes, and medical scenarios.

A systematic review methodology was employed to gather relevant literature and projects related to the applications of VR and Kinect sensors in healthcare. Databases such as Google Scholar, IEEE Xplore, and PubMed were searched for articles and studies published between 2013 and 2022. Keywords included "Virtual Reality," "Kinect Sensor," "Healthcare," "Biomedical," "Medical Applications," and related terms. Studies were selected based on relevance to the topic and their contributions to the field.

For example, the paper by Kassem et al. introduces a smart digital medical bed called MedBed, designed to address critical issues in hospitals related to timely nurse intervention and patient independence. MedBed is intended to give patients autonomy and enable them to take necessary actions when nurses are unavailable. The bed incorporates features ranging from basic to highly impactful on the patient's vital status. It allows voice commands from the patient and communicates as part of the Internet of Things (IoT) through a user-friendly smartphone application. A database is included to track activities such as medication and reminders. MedBed can be implemented in medical centers with minimal infrastructure changes [16].

Hesham A. Alabbasi et al. in their research [17], aim to utilize facial emotion recognition and brain activity to detect facial expressions and identify the corresponding brain regions in stroke patients with limited verbal communication. The proposed method involves tracking the patient's face and using the recorded coordinates to classify facial expressions through a neural network in Matlab. The results are displayed on the screen, and while initially focused on stroke patients, the approach can be extended to monitor individuals with conditions like Alzheimer's or dementia. A minimal set of 17 features was used to optimize efficiency to recognize eight emotion expressions. At the same time, future work involves expanding the database to include a more diverse range of individuals for improved recognition.

Lohse et al. reviewed the effectiveness of VR therapy in stroke survivors using custom-built virtual environments (VE) and commercially available gaming systems (CG). Out of the twenty-six studies included, the results showed that VR therapy was significantly more effective than conventional therapy in improving body function and activity outcomes. No significant differences were found between VE and CG interventions for these outcomes. However, participation outcomes were mainly derived from VE studies, indicating moderate improvements in VR rehabilitation compared to conventional therapy [2].

Thomas et al. present a modified smart wheelchair to support individuals with restricted mobility. It is based on a commercially available manual wheelchair but includes additional features such as a stereo depth camera, LIDAR, DC gear motor, joystick, and processors. Users have the flexibility to control the wheelchair manually using a joystick or hands-free through a specially developed application. The wheelchair has a Jetson processor, enabling it to navigate autonomously within indoor environments and reach the desired destination. While initially designed for hospitals, this affordable and lightweight wheelchair has the potential to be used in various indoor settings. The project also provides open-source design files, allowing for replication and accessibility to a broader audience [18].

A study by Ivan Yong-Sing, Lau et al. [19] proposed a knee osteoarthritis severity diagnostics system for gait analysis. The researchers collaborated with Sibu Hospital and KPJ Sibu Specialist Hospital to collect subject data. The study utilized the law of cosine and dot cross product as primary measures to analyze gait parameters of the knee, ankle, and hip. The proposed system successfully captures subject movement using the Microsoft Kinect v2 sensor and demonstrates an analysis algorithm for various gait parameters. Future work includes enhancing the system with machine learning algorithms to determine the severity grade of knee osteoarthritis.

The utilization of Kinect extends to supporting the diagnosis and treatment of Scoliosis [20]. For Alzheimer's disease detection, a method is proposed that utilizes a Kinect V.2 camera and machine learning to evaluate the Timed Up and Go (TUG) test and differentiate individuals with Alzheimer's disease (AD) from healthy controls (HC) [21]. Data on joint positions were gathered from both HC and AD participants, and features were extracted from various TUG subtasks. Significant features were identified through statistical analysis and machine learning that could effectively distinguish AD from HC. This approach demonstrates promise as an accessible and convenient tool for early-stage AD assessment.

As part of a system that enables real-time supervision and monitoring of patients in Intensive Care Units (ICU) within hospital settings, the Kinect sensor is equipped with a range of sensors that track patients' movements, recognize faces and process speech. These sensors do not require physical contact with the patients and instead utilize a Natural User Interface to detect skeletal movements [22].

Limin and Peiyi proposed a gesture recognition method based on LabVIEW and utilizing the 3D somatosensory camera of Kinect for controlling a medical service robot. It tracks human skeleton points, captures real-time human actions, and identifies different body actions on the LabVIEW platform. The Kinect sensor comprises various components such as a primary camera, infrared emitter, infrared depth image camera, rotatable support, and matrix microphone. It captures depth images, colour images, and sound to identify human body movements. The method enables effective human–computer interaction and provides convenience for assistant doctors in completing patient rehabilitation and nursing tasks [23].

In 2022, Amira Gaber et al. developed a system for evaluating facial paralysis (FP), including assessment and classification [24]. The system uses the Kinect V2 sensor to extract real-time facial animation units (FAUs) and employs artificial intelligence and machine learning techniques for classification. A dataset of 375 records from 13 FP patients and 1650 records from 50 control subjects was used to classify seven FP categories, including three severity levels for each side of the face. An ensemble learning classifier based on SVMs was developed to achieve high prediction accuracy. The study demonstrates the effectiveness of using FAUs acquired by the Kinect sensor for classifying FP and highlights the advantages of the developed system over existing grading scales.

Zaid A. Munder and Jiaofei Zhong explore using of a mobile robot and Kinect sensor to develop an intelligent system capable of monitoring and detecting hazardous events such as falls [25]. The Kinect sensor, integrated with the mobile robot, is used to track and detect when a person falls. When a fall is detected, the system sends SMS notifications and makes emergency calls using a mobile phone installed on the robot. The use of depth cameras, such as the Kinect sensor, offers advantages over traditional RGB cameras, providing improved performance, lower costs, and resilience to changes in lighting conditions.

In [26], using Kinect extends to assist blind individuals in navigation by using real-time depth data. The system can detect various environmental patterns, such as obstacles, walls, and stairs. These tasks pose challenges when relying on direct operation by a clinician. However, limitations exist regarding the Kinect sensor's portability and its challenges when capturing depth information in outdoor environments exposed to sunlight or water.

A Microsoft Kinect sensor system has been suggested for exercise control in physiotherapy patients [27]. It adeptly analyzes joint orientations and evaluates muscle group forces, as evidenced by successful experimental outcomes. Moreover, the method holds the potential for exercise control and monitoring applications. The study emphasizes joint range of motion detection and muscle group load analysis, employing the dot product technique for precise angle calculation. However, the system has not been entailed with a 3D virtual instructor, integrating voice commands and visual movements.

Another method proposes a personal coaching system using a Microsoft Kinect Sensor to monitor and ensure the correct execution of physiotherapy exercises at home [28]. The system includes an exercise-detection algorithm, a recognition module, and a user-friendly web interface. The results demonstrate the successful use of the system for remote physiotherapy exercises, particularly valuable during the COVID-19 pandemic. The Kinect Sensor, known for its movement and speech recognition capabilities, tracks joint coordinates and offers static and dynamic exercises. The system shows promise for remote physiotherapy, and future work aims to integrate it into more advanced virtual coaching systems involving social robots and Ambient Assisted Living environments.

An approach included a system that utilizes gesture recognition of upper body limb movements using the Kinect sensor [29]. The system drives a mobile robotic arm as a prototype. It can be extended to trigger various services for elderly and wheelchair users to help them in their daily activities. The Kinect sensor captures 3D skeleton positions, which are processed by the software tool and converted into data for the microcontroller.

Table 1 showcases additional applications of Kinect sensors within the biomedical and healthcare environment.

Several studies have demonstrated the feasibility and effectiveness of Kinect sensors in medical diagnostic tasks. For instance, Sooklal et al. (2014) explored the detection of tremors using Kinect, providing a potential non-invasive tool for diagnosing conditions like Parkinson's disease [6]. Similarly, Stone et al. (2014) developed a Kinect-based system that generates health alerts from gait measurements, enabling early detection of health changes in gait patterns [31]. These applications showcase the potential of Kinect technology to aid in the assessment and monitoring of various medical conditions.

In the context of Parkinson's disease, Amini Maghsoud Bigy et al. (2015) developed a real-time monitoring system using Kinect to detect Freezing of Gait, tremor, and fall incidents [41]. Their work highlights the potential of Kinect sensors to track joint positions and movements for symptom detection and monitoring. Ren et al. (2019) introduced a multivariate analysis method using Kinect data for Parkinson's disease assessment, demonstrating accuracy in classifying different impairment levels [40]. These studies exemplify the utility of Kinect sensors in advancing the field of medical diagnostics, enabling non-invasive and remote monitoring of various symptoms and conditions.

Kinect technology has shown promise in the realm of rehabilitation and physiotherapy, providing innovative solutions for exercise guidance and assessment. Vogiatzaki et al. (2014) developed a game-based tele-rehabilitation system using Kinect, aiming to enhance stroke patient rehabilitation remotely [32]. Similarly, Saratean et al. (2020) developed a remote physiotherapy application utilizing Kinect, which enabled exercise detection and guidance for patients while allowing physiotherapists to track progress through a web interface [28]. These studies emphasize

Table 1 Applications of Kinect sensor within biomedical and healthcare

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Healthcare	2018	Gavrilova et al. [30]	Explore applications of Kinect sensors for gesture and activity recognition in various contexts	Utilized Kinect's capabilities to capture gesture and activity data	Addressed the potential of Kinect sensors for various applications in healthcare, consumer electronics, and cognitive systems	Individuals performing gestures and activities	Demonstrated Kinect's potential in applications ranging from smart homes to biometric surveillance	Acknowledged challenges of context-based recognition and data privacy
Medical diagnostic	2014	Sooklal et al. [6]	Detect tremors using Kinect	Simulation of tremors, Kinect data capture	Detect Parkinsonian, postural, voice tremors	Accuracy in detecting head tremors, sensitivity to background movement	Kinect sensor, tremors	Potential for home monitoring and therapy
Medical diagnostic	2014	Stone et al. [31]	Generate health alerts from gait measurements	Kinect-based gait measurement system	Early detection of health changes in gait patterns	Modeling uncertainty in gait parameter estimates	Gait measurement system	Alerts for potential health issues
Rehabilitation	2014	Vogiatzaki et al. [32]	Develop game-based tele-rehabilitation system	Kinect, virtual reality, cloud-based system	Game-based rehabilitation for stroke patients	Remote exercise monitoring, bio-feedback	Tele-rehabilitation system	Enhance stroke patient rehabilitation

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Medical diagnostic, rehabilitation	2015	Pineda-Lopez et al. [33]	Develop gait analysis system using Kinect	Kinect sensor, database system	Gait analysis and visualization	Diagnosing walking problems, rehabilitation	Human body movement analysis	Gait cycle classification
Rehabilitation	2016	Pathirana et al. [34]	Develop real-time tele-rehabilitation system	Kinect, multiple devices, Kalman filter	Accurate joint position estimation	Robust bio-kinematic tracking	Tele-rehabilitation system	Improved movement tracking
Medical diagnostic	2017	Tanaka and Sogabe [35]	Measure and classify leg shapes	Kinect sensor, algorithm	Automated leg shape measurement	Classify genu valgum and genu varum	Leg shapes, Kinect sensor	Accurate leg shape classification
Medical diagnostic	2013	Shao et al. [36]	Introduce Kinect-like sensors for computer vision applications	Reviewed applications of Kinect-like sensors for computer vision	Explored the potential of Kinect-like sensors in computer vision applications	RGB-D sensor applications in computer vision	Highlighted advancements in object recognition, 3D mapping, and scene classification	Addressed challenges in depth computation and fusion
Medical diagnostic	2017	Jawaid and Qureshi [3]	Review of Kinect-based medical imaging applications	Explored applications of Kinect for medical imaging tasks	Highlighted Kinect's use in medical imaging for diagnostics and treatments	Medical imaging using Kinect	Demonstrated Kinect's applications in medical diagnostics	Addressed challenges of noise, accuracy, and sensor fusion

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Medical diagnostic	2018	Eltoukhy et al. [37]	Validate Kinect v2 sensor for assessing balance in both young and elderly populations	Utilized Kinect v2 to capture balance-related data during static and dynamic tasks	Addressed limitations in assessing balance accurately and conveniently	Young and elderly participants performing balance tasks	Kinect v2 provided valid measurements of balance-related parameters for both age groups	Limitations included small sample size and challenges in temporal variations
Medical diagnostic	2019	Saraguro et al. [38]	Develop a system to analyze hand movements in PD patients using Kinect	Utilized Kinect V2 sensor, tracked hand movements for PD evaluation	Provided non-invasive tool for evaluating PD progression via finger tapping tests	Hand movements of PD patients	Detected lower tapping velocity in upper right extremities of PD patients	Variation in medication status, sensitivity to disease severity
Medical diagnostic	2019	Dehbandi et al. [39]	Explore the feasibility of using Kinect 2 data for quantifying upper limb behavior in motor disorders	Developed a method to quantify joint motion data using Kinect 2	Addressed limitations in accurately capturing motor symptoms and movement patterns in motor disorders	Participants with and without motor disorders performing sit-to-stand-to-sit motion	Proposed method showed exceptional classification performance for distinguishing healthy and motor disorder participants	Challenges included computational demands of the method and broader assessment of motor symptoms

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Training	2017	Limin and Peiyi [23]	Develop a gesture recognition method for controlling a medical service robot using Kinect	Kinect technology, LabVIEW software	Enhancing human–computer interaction in medical service robots	Medical service robot	Successful human–computer interaction for controlling medical service robots in healthcare settings	Acknowledges limitations of Kinect positioning and potential accuracy issues due to environmental factors
Medical diagnostic	2019	Ren et al. [40]	Introduce a multivariate analysis method using Kinect data for Parkinson's disease assessment	Developed a method to analyze joint motion data using Kinect for Parkinson's disease assessment	Addressed limitations in accurately capturing motor symptoms in Parkinson's disease	Healthy participants and Parkinson's disease patients performing sit-to-stand-to-sit motion	Proposed method demonstrated accuracy in classifying Parkinson's disease impairment levels	Challenges included computational demands and limited assessment of motor symptoms

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Monitoring, medical diagnostic	2015	Amini Maghsoud Bigy et al. [41]	Develop a Kinect-based system for real-time monitoring and detection of Freezing of Gait, tremor, and fall incidents in Parkinson's disease patients	Utilized Kinect sensor to track joint positions and movements for symptom detection	Addressed challenges of detecting critical incidents in Parkinson's disease patients	Parkinson's disease patients exhibiting various symptoms	Demonstrated Kinect's potential for detecting FOG, tremor, and falls with promising accuracy	Limitations included simulated subjects and potential tracking errors
Physiotherapy	2017	Cubukcu and Yuzgec [42]	Develop a Kinect-based physiotherapy application for patients with shoulder joint, muscle, and tendon damage	Created a physiotherapy application using Kinect for exercise guidance and assessment	Addressed difficulties in accessing physiotherapy centers and performing exercises correctly	Patients with shoulder joint, muscle, and tendon damage	Demonstrated the potential of Kinect-based application for remote physiotherapy guidance	Limitations included focusing on specific conditions and lack of interactive communication
Physiotherapy	2020	Saratean et al. [28]	Develop a system for remote physiotherapy using Kinect	Utilized Kinect Sensor for exercise detection, web interface for physiotherapists	Supported remote physiotherapy through exercise guidance and tracking	Physiotherapy exercises	Detected exercise correctness and guided patients remotely	Limitation in tracking obscured joints, Kinect's field of view limitation

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Physiotherapy	2020	Huang et al. [43]	Develop a Kinect-based self-help training system for nursing students to learn patient transfer skills	Utilized Kinect RGB-D sensors to measure trainee and patient postures for skill evaluation	Addressed the limitations of traditional nursing education for patient transfer skills	Nursing students learning patient transfer skills	Demonstrated accuracy and effectiveness of the system for improving patient transfer skills	Addressed tracking errors and potential challenges in evaluation
Rehabilitation	2014	Gauthier and Cretu [44]	Develop a Kinect-based system for monitoring and assessing exercise performance in home-based settings	Utilized Kinect to track joint movements and quantify exercise performance	Addressed limitations in monitoring exercise performance and adherence in home environments	Individuals performing physical exercise at home	Demonstrated the feasibility of using Kinect for quantifying exercise movements and providing feedback	Limitations included simplified joint model and potential measurement errors
Rehabilitation	2015	Lai et al. [45]	Develop a Kinect-based system for virtual rehabilitation to train balance in stroke patients	Utilized Kinect V1 to create a virtual rehabilitation system	Addressed limitations of in-person rehabilitation for stroke patients by providing a home-based training solution	Stroke patients performing balance training exercises	Significant improvements in balance-related parameters for stroke patients using the Kinect-based system	Challenges included further exploration of exercises and ensuring consistent participation

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Medical education	2015	Pauly et al. [46]	Improve surgical scene understanding	Augmented reality using Kinect and X-ray data fusion	Enhance spatial understanding in orthopedic surgery	Augmented reality setup	Improved surgical scene understanding, depth perception enhancement	Challenges in object recognition using color and depth cues
Rehabilitation	2017	Park et al. [47]	Assess VR training effects on motor recovery	Virtual reality training with Xbox Kinect	Improve motor function and recovery in stroke survivors	Stroke survivors	VR training improved motor function, efficient instrument movement	Discrepancy in intervention time, Kinect recognition errors
Medical education	2018	Feng et al. [48]	Evaluate Virtual Pointer in laparoscopic training	Virtual Pointer system using Kinect for guidance	Enhance professional vision in laparoscopic surgical training	Surgical trainees	Virtual Pointer improved perception and economy of movement	No significant reduction in errors or time to completion
Medical services	2014	Kim et al. [49]	Compare Kinect hand tracking to mechanical control	Kinect hand tracking technology for surgical robots	Explore feasibility of Kinect-based control for surgical robots	Experienced surgeons	Kinect hand tracking is promising but needs improvement	Latency and static noise affecting performance
Rehabilitation, monitoring	2014	Saiyi Li et al. [50]	Improve Kinect-based rehabilitation monitoring	Multi-Kinect fusion for joint position measurement	Enhance accuracy of joint position measurement in rehab monitoring	Rehabilitation patients	Improved joint position measurement accuracy	Noise in Kinect data, limited dataset size

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Medical services	2017	Xiao et al. [51]	Develop Kinect-based navigation system	Optical navigation using Kinect camera	Enhance accuracy of needle insertion in abdominal interventions	Phantom and animal experiments	Accurate needle placement, better accuracy with Kinect V2	Complexity of workflow, need for respiratory compensation
Medical education	2022	Fuchs et al. [52]	Develop evaluation system for endoscopic training	Multimodal feature combination using Kinect and EMG	Evaluate learning benefits of stereoscopic views in training	Surgical trainees	Validated simulator-independent endoscopic skill assessment	Small dataset size, need for more extensive training

the potential of Kinect-based systems to support rehabilitation and physiotherapy efforts by offering remote guidance and monitoring capabilities.

Lai et al. (2015) developed a Kinect-based virtual rehabilitation system to train balance in stroke patients, providing an alternative to in-person rehabilitation [45]. The findings suggest significant improvements in balance-related parameters for stroke patients using the Kinect-based system. Additionally, Cubukcu and Yuzgec (2017) created a Kinect-based physiotherapy application for patients with shoulder joint, muscle, and tendon damage, offering exercise guidance and assessment outside of traditional healthcare settings [42]. These studies highlight the potential of Kinect technology to revolutionize the field of rehabilitation, making exercise guidance and assessment more accessible and convenient for patients.

In the realm of surgical training and education, Kinect technology has been explored to enhance surgical skills and professional vision. Feng et al. (2018) evaluated the effectiveness of the Virtual Pointer system in improving laparoscopic surgical training by using Kinect for visual guidance [48]. The results indicated improved perception and economy of movement, enhancing trainees' adoption of professional vision. Moreover, Kim et al. (2014) investigated the feasibility of using Kinect-based hand tracking technology for controlling surgical robots, showcasing its potential to revolutionize surgical control methods [49]. These studies illustrate the potential of Kinect technology to enhance surgical training and control systems, offering innovative solutions to improve skill development and performance.

These applications above show that VR has positively impacted the biomedical field and healthcare environment. The application of VR will continue to develop and experience further improvements to help improve diagnosis, therapy, health education, and many more.

3.1 Challenges and Opportunities in the Use of VR and Kinect Sensor

While the integration of VR and Kinect technology holds promise in healthcare, there are challenges to consider. Accuracy [41], potential tracking errors [3, 44], and computational demands [40] are among the limitations identified in various studies. Additionally, the adoption of these technologies in clinical settings requires careful consideration of patient safety, data privacy [30], and effective integration into existing healthcare workflow.

The algorithm's performance might vary based on individual characteristics, and further refinements and real-time testing are needed to validate its reliability. The study also acknowledged the possibility of false positives or missed alerts and emphasized the importance of parameter tuning by clinicians [31, 53].

The accurate and reliable capture of data stands as a central challenge in applications reliant on both Virtual Reality (VR) and Kinect-based technology. The studies underscore the critical demand for precision in tracking movements, particularly within clinical contexts where precise data is imperative for diagnostic and therapeutic purposes. The calibration and setup of Kinect sensors represent essential factors in attaining accurate data [54]. Ensuring the precise positioning and orientation of these sensors can prove challenging, particularly when dealing with home-based environments. Additionally, the presence of environmental variables, occlusions, and noise within depth data [6] can significantly impact the accuracy of tracking and recognition algorithms. The resolution of these issues is of paramount importance to establish dependable and consistent outcomes.

The development of robust algorithms to facilitate gesture recognition, movement tracking, and pose estimation [53] introduces a complex undertaking. This necessitates careful consideration of numerous factors, including the selection of appropriate machine learning models and feature extraction techniques. Furthermore, the diverse nature of human anatomy and movements across individuals accentuates the need for algorithms and systems that can adeptly adapt to accommodate these differences. This ensures the technology's effectiveness across a wide spectrum of users.

Real-time processing [32], especially in applications like tele-rehabilitation and human–robot interaction, introduces challenges due to the requisite low latency and immediate feedback. The integration of VR and Kinect-based systems into established clinical practices mandates validation, regulatory compliance, and alignment with healthcare standards. Clinicians seek assurance regarding the technology's precision, safety, and efficacy, thereby emphasizing the need for comprehensive validation and adherence to industry regulations.

While using virtual reality (VR) and the Kinect sensor has challenges in various fields, it also brings numerous opportunities. VR and Kinect technologies present a remarkable avenue for remote monitoring and rehabilitation, enabling patients to seamlessly engage in therapy from the comfort of their homes. This holds the potential to ameliorate patient compliance and alleviate the strain on healthcare facilities. Integrating gamification and interactive exercises into rehabilitation programs imparts an engaging and motivating dimension. The immersive qualities of VR, coupled with the natural interaction facilitated by Kinect sensors, synergistically contribute to heightened patient adherence and participation rates.

Beyond patient engagement, the amalgamation of VR and Kinect-based systems yields a trove of movement data that can be systematically analyzed to yield insights into patient progress, movement patterns, and avenues for potential enhancement. This data-centric approach paves the way for personalized rehabilitation regimens that cater to individual needs.

A distinctive advantage of Kinect sensors lies in their cost-effectiveness as a depth-sensing solution, particularly when juxtaposed with more intricate motion capture systems. The affordability of Kinect sensors extends opportunities for broader adoption, particularly in settings with resource constraints. The meticulous tracking and detailed movement analysis facilitated by Kinect sensors hold profound diagnostic potential for identifying movement disorders and evaluating the efficacy of treatments. Moreover, VR-based diagnostic tools, enriched by Kinect data, proffer clinicians with invaluable insights to inform their decision-making.

VR and Kinect systems exhibit remarkable adaptability, allowing interventions to be tailored to individual progress and capabilities. This adaptiveness, in conjunction with the synergy between VR and Kinect, extends beyond rehabilitation to enrich human–robot interaction. The fusion of these technologies empowers robots to comprehend and respond to human gestures and movements with heightened intuition, fostering a more seamless interaction between humans and machines.

The collective studies underscore the strides made in the field, yet concurrently emphasize the expansive realm for further research and innovation. The path forward beckons the development of novel algorithms, the refinement of existing technologies, and the exploration of untapped applications. As these technologies mature, the marriage of VR and Kinect is poised to revolutionize healthcare, offering solutions that transcend physical boundaries and cater to individual needs with unprecedented precision.

While the studies presented valuable insights, there are several limitations to consider. First, the reviewed studies relied on relatively small sample sizes, limiting the generalizability of the findings. The studies predominantly focused on specific medical conditions, potentially excluding broader applications. Furthermore, the challenges related to VR and Kinect technology, such as hardware limitations and user comfort, were not always extensively explored within the reviewed studies.

4 Conclusion

Virtual reality (VR) has significantly changed various industries, including biomedical and health. By immersing individuals in computer-generated environments, VR offers interactive and immersive experiences, and its applications extend beyond being a medium or advanced user interface. VR has practical solutions to real-world challenges, and its effectiveness relies on immersion, interaction, and imagination. The history of VR spans over 40 years, with significant advancements in hardware and software components. The Kinect sensor, initially developed for gaming, has found applications in biomedical and health fields, such as diagnostic tasks, monitoring of various medical conditions, rehabilitation and physiotherapy, surgical training and education. While challenges exist, VR and the Kinect sensor provide opportunities for personalized interventions, remote healthcare delivery, training, collaboration, and improved patient engagement. As technology evolves, the potential of VR and the Kinect sensor in healthcare is expected to grow, with a focus on managing costs, enhancing hardware capabilities, ensuring data security, and refining user experiences.

References

1. Pensieri C, Pennacchini M (2016) Virtual reality in medicine. https://doi.org/10.1007/978-3-319-22041-3_14
2. Lohse KR, Hilderman CGE, Cheung KL, Tatla S, Van der Loos HFM (2014) Virtual reality therapy for adults post-stroke: a systematic review and meta-analysis exploring virtual environments and commercial games in therapy. PLoS ONE 9:e93318. https://doi.org/10.1371/journal.pone.0093318
3. Jawaid I, Qureshi JK (2017) Advancements in medical imaging through Kinect: a review. In: 2017 international symposium on wireless systems and networks (ISWSN). IEEE, pp 1–5. https://doi.org/10.1109/ISWSN.2017.8250032
4. Dargar S, Nunno A, Sankaranarayanan G, De S (2013) Microsoft Kinect based head tracking for life size collaborative surgical simulation environments (LS-CollaSSLE). Stud Health Technol Inform 184:109–113
5. Palter VN, Grantcharov TP (2010) Virtual reality in surgical skills training. Surg Clin North Am 90:605–617. https://doi.org/10.1016/j.suc.2010.02.005
6. Sooklal S, Mohan P, Teelucksingh S (2014) Using the Kinect for detecting tremors: challenges and opportunities. In: IEEE-EMBS international conference on biomedical and health informatics (BHI). IEEE, pp 768–771. https://doi.org/10.1109/BHI.2014.6864477
7. Suarez J, Murphy RR (2012) Hand gesture recognition with depth images: a review. In: 2012 IEEE RO-MAN: the 21st IEEE international symposium on robot and human interactive communication. IEEE, pp 411–417. https://doi.org/10.1109/ROMAN.2012.6343787
8. Burdea GC, Coiffet P (2003) Virtual reality technology. Wiley
9. Burdea GC (1999) Invited review: the synergy between virtual reality and robotics. IEEE Trans Robot Autom 15:400–410. https://doi.org/10.1109/70.768174
10. Zhang Z (2012) Microsoft Kinect sensor and its effect. IEEE Multimed 19:4–10. https://doi.org/10.1109/MMUL.2012.24
11. Yang L, Zhang L, Dong H, Alelaiwi A, El Saddik A (2015) Evaluating and improving the depth accuracy of Kinect for Windows v2. IEEE Sens J 15:4275–4285. https://doi.org/10.1109/JSEN.2015.2416651
12. El-laithy RA, Huang J, Yeh M (2012) Study on the use of Microsoft Kinect for robotics applications. In: Proceedings of the 2012 IEEE/ION position, location and navigation symposium. IEEE, pp 1280–1288. https://doi.org/10.1109/PLANS.2012.6236985
13. Correa DSO, Sciotti DF, Prado MG, Sales DO, Wolf DF, Osório FS (2012) Mobile robots navigation in indoor environments using Kinect sensor. In: Proceedings - 2012 2nd Brazilian conference on critical embedded systems, CBSEC 2012, pp 36–41. https://doi.org/10.1109/CBSEC.2012.18
14. Eric N, Jang J-W (2017) Kinect depth sensor for computer vision applications in autonomous vehicles. In: 2017 ninth international conference on ubiquitous and future networks (ICUFN). IEEE, pp 531–535. https://doi.org/10.1109/ICUFN.2017.7993842
15. Clark RA, Pua Y-H, Oliveira CC, Bower KJ, Thilarajah S, McGaw R, Hasanki K, Mentiplay BF (2015) Reliability and concurrent validity of the Microsoft Xbox One Kinect for assessment of standing balance and postural control. Gait Posture 42:210–213. https://doi.org/10.1016/j.gaitpost.2015.03.005
16. Kassem A, Hamad M, El Moucary C, Nawfal E, Aoun A (2017) MedBed: smart medical bed. In: 2017 Fourth international conference on advances in biomedical engineering (ICABME). IEEE, pp 1–4. https://doi.org/10.1109/ICABME.2017.8167544
17. Alabbasi HA, Moldoveanu F, Moldoveanu A, Shhedi Z (2015) Facial emotion expressions recognition with brain activites using Kinect sensor V2. Int Res J Eng Technol
18. Sola-Thomas E, Baser Sarker MA, Caracciolo MV, Casciotti O, Lloyd CD, Imtiaz MH (2021) Design of a low-cost, lightweight smart wheelchair. In: 2021 IEEE microelectronics design and test symposium, MDTS 2021. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/MDTS52103.2021.9476093

19. Lau IY-S, Chua T-T, Lee WX-P, Wong C-W, Toh T-H, Ting H-Y (2020) Kinect-based knee osteoarthritis gait analysis system. In: 2020 IEEE 2nd international conference on artificial intelligence in engineering and technology (IICAIET). IEEE, pp 1–6. https://doi.org/10.1109/IICAIET49801.2020.9257860
20. Cukovic S, Petruse RE, Meixner G, Buchweitz L (2020) Supporting diagnosis and treatment of scoliosis: using augmented reality to calculate 3D spine models in real-time - ARScoliosis. In: 2020 IEEE international conference on bioinformatics and biomedicine (BIBM). IEEE, pp 1926–1931. https://doi.org/10.1109/BIBM49941.2020.9313200
21. Seifallahi M, Mehraban AH, Galvin JE, Ghoraani B (2022) Alzheimer's disease detection using comprehensive analysis of timed up and go test via Kinect vol 2 Camera and machine learning. IEEE Trans Neural Syst Rehabil Eng 30:1589–1600. https://doi.org/10.1109/TNSRE.2022.3181252
22. Shehabat IM, Al-Hussein N (2018) Deploying internet of things in healthcare: benefits, requirements, challenges and applications. J Commun 574–580. https://doi.org/10.12720/jcm.13.10.574-580
23. Limin M, Peiyi Z (2017) The medical service robot interaction based on Kinect. In: 2017 IEEE international conference on intelligent techniques in control, optimization and signal processing (INCOS). IEEE, pp 1–7. https://doi.org/10.1109/ITCOSP.2017.8303077
24. Gaber A, Taher MF, Wahed MA, Shalaby NM, Gaber S (2022) Classification of facial paralysis based on machine learning techniques. Biomed Eng Online 21:65. https://doi.org/10.1186/s12938-022-01036-0
25. Mundher ZA, Jiaofei Z (2014) A real-time fall detection system in elderly care using mobile robot and Kinect sensor. Int J Mater Mech Manuf 2:133–138. https://doi.org/10.7763/IJMMM.2014.V2.115
26. Filipe V, Fernandes F, Fernandes H, Sousa A, Paredes H, Barroso J (2012) Blind navigation support system based on Microsoft Kinect. Procedia Comput Sci 14:94–101. https://doi.org/10.1016/j.procs.2012.10.011
27. Topuz B, Ozuag E, Akbulut O (2016) Kinect sensor based physiotherapy management. In: 2016 24th signal processing and communication application conference (SIU). IEEE, pp 2209–2212. https://doi.org/10.1109/SIU.2016.7496213
28. Saratean T, Antal M, Pop C, Cioara T, Anghel I, Salomie I (2020) A physiotheraphy coaching system based on Kinect sensor. In: 2020 IEEE 16th international conference on intelligent computer communication and processing (ICCP). IEEE, pp 535–540. https://doi.org/10.1109/ICCP51029.2020.9266178
29. Ababneh M, Shaban H, AlShalabe D, Khader D, Mahameed H, AlQudimat M (2018) Gesture controlled mobile robotic arm for elderly and wheelchair people assistance using Kinect sensor. In: 2018 15th international multi-conference on systems, signals and devices (SSD). IEEE, pp 636–641. https://doi.org/10.1109/SSD.2018.8570547
30. Gavrilova ML, Wang Y, Ahmed F, Polash Paul P (2018) Kinect sensor gesture and activity recognition: new applications for consumer cognitive systems. IEEE Consum Electron Mag 7:88–94. https://doi.org/10.1109/MCE.2017.2755498
31. Stone EE, Skubic M, Back J (2014) Automated health alerts from Kinect-based in-home gait measurements. In: 2014 36th annual international conference of the IEEE engineering in medicine and biology society. IEEE, pp 2961–2964. https://doi.org/10.1109/EMBC.2014.6944244
32. Vogiatzaki E, Gravezas Y, Dalezios N, Biswas D, Cranny A, Ortmann S, Langendorfer P, Lamprinos I, Giannakopoulou G, Achner J, Klemke J, Jost H (2014) Telemedicine system for game-based rehabilitation of stroke patients in the FP7-"StrokeBack" project. In: 2014 European conference on networks and communications (EuCNC). IEEE, pp 1–5. https://doi.org/10.1109/EuCNC.2014.6882688
33. Pineda-Lopez FM, Flores CMJ, Ortiz VGJ, Mosquera YWA (2015) Prototype for the analysis of human body movement with Kinect sensor. In: 2015 20th symposium on signal processing, images and computer vision (STSIVA). IEEE, pp 1–7. https://doi.org/10.1109/STSIVA.2015.7330410

34. Pathirana PN, Li S, Trinh HM, Seneviratne A (2016) Robust real-time bio-kinematic movement tracking using multiple Kinects for tele-rehabilitation. IEEE Trans Industr Electron 63:1822–1833. https://doi.org/10.1109/TIE.2015.2497662
35. Tanaka M, Sogabe A (2017) A measuring system of the legs shape by using the Kinect sensor. In: 2017 56th annual conference of the society of instrument and control engineers of Japan (SICE). IEEE, pp 106–109. https://doi.org/10.23919/SICE.2017.8105558
36. Shao L, Han J, Xu D, Shotton J (2013) Computer vision for RGB-D sensors: Kinect and its applications [special issue intro]. IEEE Trans Cybern 43:1314–1317. https://doi.org/10.1109/TCYB.2013.2276144
37. Eltoukhy MA, Kuenze C, Oh J, Signorile JF (2018) Validation of static and dynamic balance assessment using Microsoft Kinect for young and elderly populations. IEEE J Biomed Health Inform 22:147–153. https://doi.org/10.1109/JBHI.2017.2686330
38. Saraguro W, Barzallo B, Guillermo J, Garcia-Cedeno A, Soto A, Rivas D, Clotet R, Huerta M (2019) Analysis of hand movements in patients with Parkinson's disease using Kinect. In: 2019 IEEE international conference on e-health networking, application and services (HealthCom). IEEE, pp 1–6. https://doi.org/10.1109/HealthCom46333.2019.9009589
39. Dehbandi B, Barachant A, Harary D, Long JD, Tsagaris KZ, Bumanlag SJ, He V, Putrino D (2017) Using data from the Microsoft Kinect 2 to quantify upper limb behavior: a feasibility study. IEEE J Biomed Health Inform 21:1386–1392. https://doi.org/10.1109/JBHI.2016.2606240
40. Ren P, Bosch Bayard JF, Dong L, Chen J, Mao L, Ma D, Sanchez MA, Morejon DM, Bringas ML, Yao D, Jahanshahi M, Valdes-Sosa PA (2020) Multivariate analysis of joint motion data by Kinect: application to Parkinson's disease. IEEE Trans Neural Syst Rehabil Eng 28:181–190. https://doi.org/10.1109/TNSRE.2019.2953707
41. Amini Maghsoud Bigy A, Banitsas K, Badii A, Cosmas J (2015) Recognition of postures and Freezing of Gait in Parkinson's disease patients using Microsoft Kinect sensor. In: 2015 7th international IEEE/EMBS conference on neural engineering (NER). IEEE, pp 731–734. https://doi.org/10.1109/NER.2015.7146727
42. Cubukcu B, Yuzgec U (2017) A physiotherapy application with MS Kinect for patients with shoulder joint, muscle and tendon damage. In: 2017 9th international conference on computational intelligence and communication networks (CICN). IEEE, pp 225–228. https://doi.org/10.1109/CICN.2017.8319390
43. Huang Z, Nagata A, Kanai-Pak M, Maeda J, Kitajima Y, Nakamura M, Aida K, Kuwahara N, Ogata T, Ota J (2014) Self-help training system for nursing students to learn patient transfer skills. IEEE Trans Learn Technol 7:319–332. https://doi.org/10.1109/TLT.2014.2331252
44. Gauthier S, Cretu A-M (2014) Human movement quantification using Kinect for in-home physical exercise monitoring. In: 2014 IEEE international conference on computational intelligence and virtual environments for measurement systems and applications (CIVEMSA). IEEE, pp 6–11. https://doi.org/10.1109/CIVEMSA.2014.6841430
45. Lai C-L, Huang Y-L, Liao T-K, Tseng C-M, Chen Y-F, Erdenetsogt D (2015) A Microsoft Kinect-based virtual rehabilitation system to train balance ability for stroke patients. In: 2015 international conference on cyberworlds (CW). IEEE, pp 54–60. https://doi.org/10.1109/CW.2015.44
46. Pauly O, Diotte B, Fallavollita P, Weidert S, Euler E, Navab N (2015) Machine learning-based augmented reality for improved surgical scene understanding. Comput Med Imaging Graph 41:55–60. https://doi.org/10.1016/j.compmedimag.2014.06.007
47. Park D-S, Lee D-G, Lee K, Lee G (2017) Effects of virtual reality training using Xbox Kinect on motor function in stroke survivors: a preliminary study. J Stroke Cerebrovasc Dis 26:2313–2319. https://doi.org/10.1016/j.jstrokecerebrovasdis.2017.05.019
48. Feng Y, McGowan H, Semsar A, Zahiri HR, George IM, Turner T, Park A, Kleinsmith A, Mentis HM (2018) A virtual pointer to support the adoption of professional vision in laparoscopic training. Int J Comput Assist Radiol Surg 13:1463–1472. https://doi.org/10.1007/s11548-018-1792-9

49. Kim Y, Leonard S, Shademan A, Krieger A, Kim PCW (2014) Kinect technology for hand tracking control of surgical robots: technical and surgical skill comparison to current robotic masters. Surg Endosc 28:1993–2000. https://doi.org/10.1007/s00464-013-3383-8
50. Li S, Pathirana PN, Caelli T (2014) Multi-Kinect skeleton fusion for physical rehabilitation monitoring. In: 2014 36th annual international conference of the IEEE engineering in medicine and biology society. IEEE, pp 5060–5063. https://doi.org/10.1109/EMBC.2014.6944762
51. Xiao D, Luo H, Jia F, Zhang Y, Li Y, Guo X, Cai W, Fang C, Fan Y, Zheng H, Hu Q (2016) A Kinect^{TM} camera based navigation system for percutaneous abdominal puncture. Phys Med Biol 61:5687–5705. https://doi.org/10.1088/0031-9155/61/15/5687
52. Fuchs R, Van Praet KM, Bieck R, Kempfert J, Holzhey D, Kofler M, Borger MA, Jacobs S, Falk V, Neumuth T (2022) A system for real-time multivariate feature combination of endoscopic mitral valve simulator training data. Int J Comput Assist Radiol Surg 17:1619–1631. https://doi.org/10.1007/s11548-022-02588-1
53. Tellaeche A, Maurtua I (2014) 6DOF pose estimation of objects for robotic manipulation. A review of different options. In: Proceedings of the 2014 IEEE emerging technology and factory automation (ETFA). IEEE, pp 1–8. https://doi.org/10.1109/ETFA.2014.7005077
54. Bt Ismail NH, Basah SNB (2015) The applications of Microsoft Kinect for human motion capture and analysis : a review. In: 2015 2nd international conference on biomedical engineering (ICoBE). IEEE, pp 1–4. https://doi.org/10.1109/ICoBE.2015.7235894

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The Application of Virtual Reality Using Kinect Sensor in Biomedical and Healthcare Environment: A Review

Henry Candra, Umi Yuniati, and Rifai Chai

Abstract Virtual Reality (VR) and the Kinect sensor, as promising tools in biomedical research, offers diverse applications in medical education, rehabilitation, diagnostics, and health research. The problem statement highlights the demand for innovative solutions and introduces VR and Kinect as potential transformative technologies. This review analyzes the importance of these technologies, their contributions, and future potential. It stands out by evaluating various Kinect-based systems in medical settings. By highlighting distinct features, advancements, and limitations, it provides guidance for future research. Relevant literature was gathered from databases such as Google Scholar, IEEE Xplore, and PubMed. The results showcase a wide range of applications, including patient autonomy, stroke rehabilitation, diagnostics, and monitoring. Despite challenges in accurate movement tracking, integration into clinical settings, and limited generalizability of findings due to small sample sizes, VR and Kinect show potential for revolutionizing healthcare delivery and improving patient outcomes. Their adaptability, affordability, and immersive nature of these technologies offer promising avenues for personalized interventions, remote healthcare, training, and enhanced patient engagement. As these technologies evolve, continued research and development are crucial to optimize their impact in shaping the future of healthcare.

Keywords Virtual reality · Kinect sensor · Biomedical fields · Healthcare solutions

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1 Introduction

Virtual reality (VR) has become a promising biomedical research tool, showing great potential in recent years. Its applications span various areas within the field, such as in medical educational, surgical simulation, and therapy [1]. For instance, VR instruments like headsets and motion controls have been employed in rehabilitation therapy to aid patients recovering from stroke [2] and brain injuries. By allowing individuals to practice motor skills in a secure virtual environment, these systems contribute to accelerating the recovery process and improve motor function [3].

In addition to rehabilitation, VR finds utility in medical education. Medical and healthcare students can utilize VR headsets and other resources to simulate medical procedures and explore human anatomy virtually, such as surgical simulation [4]. This immersive approach enhances their training experience, providing a more realistic environment to develop their medical skills [5]. Furthermore, VR is valuable in medical diagnostics, enabling doctors to make more precise diagnoses by using data from medical imaging [3]. The mechanisms allow doctors to identify health problems and develop more effective treatment plans quickly.

Moreover, VR is vital in health research, particularly in psychology, neurology, and psychiatry. Researchers can create controlled environments using VR headsets and observe participants' responses and behaviors in simulated situations. These experiments facilitate the exploration and development of novel interventions for various health problems.

The Kinect sensor technology, as a virtual reality device, stands out for its affordability, user-friendliness, and potential for advancement in medical and healthcare applications [6] in recent years. The advent of the Kinect and associated libraries has led to increased research interest on practical applications [7].

This review aims to comprehensively analyze the role of these technologies, the contributions they make to healthcare, and their implications for the future. This study distinguishes itself by conducting a systematic comparison and analysis of a diverse range of Kinect-based systems applied to biomedical and healthcare environment. By highlighting the unique features, innovations, and limitations of each approach, this review provides a comprehensive overview that can guide future research and development efforts.

2 Virtual Reality (VR) and Kinect Sensor

2.1 Definition and History of VR

Virtual reality is a computer program that enables individuals to connect and engage with computer-generated surroundings, replicating real-life experiences and involving all the senses. It offers interactive and immersive experiences, commonly known as the two I's. However, there exists a lesser known third aspect of virtual reality. Virtual reality possesses applications that provide practical solutions to real-world challenges beyond being a medium or advanced user interface. Virtual reality professionals develop these applications. The effectiveness of a particular application, or how well a simulation performs, heavily relies on the human imagination—the third "I" of virtual reality. Thus, virtual reality represents immersion, interaction, and imagination. Vision in virtual reality also pertains to the mind's ability to perceive things that do not exist [8].

Virtual reality has a history spanning over 40 years. In 1962, Morton Heilig patented the Sensorama Simulator. This first virtual reality video arcade offered a multi-sensory experience with 3D video, motion, colour, sound, aromas, wind effects, and a vibrating seat. Sutherland's work in 1966 introduced the concept of head-mounted displays (HMDs) and the use of computer-generated scenes instead of analog images. Brooks and his colleagues later simulated force fields and collision forces using robotic arms, paving the way for today's haptic technology. The military's interest in digital simulators drove classified research, and NASA developed the Virtual Visual Environment Display (VIVED) in 1981, influencing modern VR headsets. NASA's integration of computers and trackers created the first VR system, while Scott Fisher's contributions enhanced interaction with sensing gloves and virtual sound sources. These advancements spurred international conferences and firmly established virtual reality in the scientific and engineering communities.

VPL Inc., led by Jaron Lanier, emerged as the first to sell VR products. They introduced the groundbreaking DataGlove, which revolutionized computer interaction with its fiber-optic sensors enabling gesture-based input in 1987. However, the DataGlove was expensive and lacked tactile feedback. In 1989, Nintendo released the more affordable PowerGlove, although its downfall was the limited game support. VPL also introduced the EyePhones, commercial head-mounted displays, in the late 1980s, but they suffered from low resolution and high prices. Integration challenges persisted, prompting VPL to develop the turnkey VR system, RB2 Model 2. Division Ltd. introduced the integrated VR workstation, Vision, and the consequential Provision 100 in 1992. Sense8 Co.'s WorldToolKit and Dimension International's Virtual Reality Toolkit (VRT3) addressed the software development challenges in the 1990s.

Early virtual reality (VR) hardware faced several challenges in the 1990s. The VR market was small, with most pioneering companies lacking resources for product improvements and relying on private capital. Unrealistic public expectations and funding limitations led to the disappearance of many VR companies. However, a small group of scientists continued VR research. Significant advancements in PC hardware, such as faster CPUs and graphics accelerators, facilitated VR's rebirth in the late 1990s. The performance of PC graphics matched or exceeded high-end SGI graphics supercomputers by 2001, thanks to rapid technological advances. Additionally, breakthroughs in VR interfaces, including lightweight and higher-resolution LCD-based HMDs and the introduction of large-volume displays, further contributed to the growth of the VR market.

2.2 VR Technology and Its Components

Virtual reality (VR) systems have five main components: VR Engine, Input/Output Devices, Software and Database, User, and Task [8]. The block diagram in Fig. 1 illustrated the architecture of VR [9]. VR Engine is the core software framework that powers VR experiences by rendering virtual environments, managing physics simulations, integrating tracking data, and enabling real-time interactivity. Input devices capture user interactions and movements, while output devices provide sensory feedback. Examples include motion controllers, data gloves, positional trackers, head-mounted displays (HMDs), audio systems, and haptic feedback devices. Software and databases are essential for developing, customizing, and deploying VR applications. The developments include content creation tools, simulation software, user interface systems, and APIs. A database or content management system stores virtual assets like 3D models, textures, sounds, and user data. The user is the participant who engages with the VR system through input and output devices, experiencing a sense of presence and interaction. User comfort, safety, and overall experience are crucial considerations. The task is the purpose and objectives of using VR, defining specific activities, simulations, or experiences the system aims to provide. VR applications span various domains, such as gaming, entertainment, education, training, and scientific research. The task component guides the design and development of the virtual environment and user interactions to support the intended use case.

Through the seamless integration of these five components, virtual reality systems generate attractive and interactive encounters, transporting users to simulated realms where they can explore, interact, and engage in manners surpassing the physical world's limitations.

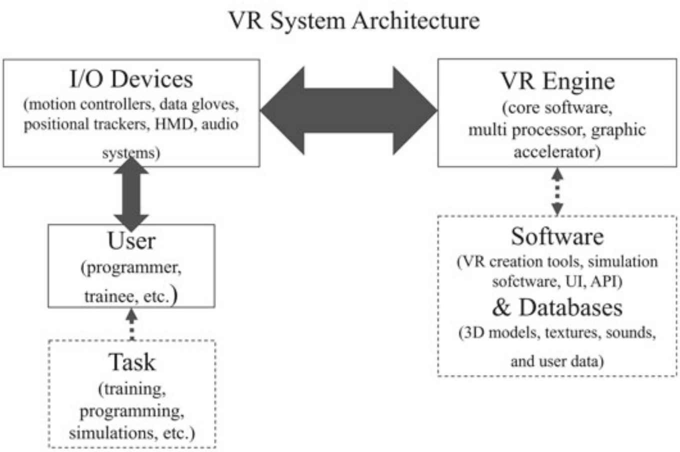

Fig. 1 The five components of a VR system

2.3 The Role of Kinect Sensor in VR

The Kinect sensor is a motion-sensing input device initially developed by Microsoft for gaming on the Xbox console. Kinect sensor V1, released in 2010, utilized infrared depth sensing, an RGB camera, and microphones to capture motion and audio data [10]. It allowed users to control games and menus through body movements and voice commands. Kinect Sensor V2, introduced in 2014, offers improved depth and image sensors, which may enhance its accuracy in assessing postural control and balance impairments. Both versions employed skeletal tracking technology, enabling immersive interactions through gestures, voice, and facial recognition. However, Kinect V2 provided better performance and advanced features, making it the preferred choice for users and developers in virtual reality, gaming, and other applications [11].

While it was primarily designed for gaming, the Kinect sensor has also found applications in VR systems. Known as a depth camera, it revolutionizes robot perception worldwide, replacing traditional cameras and range finders. Its depth-sensing capabilities enable detailed environment understanding and map generation, setting it apart from other vision systems. The Kinect sensor's ability to capture high-quality images and depth information about the environment at an affordable price has led to its widespread adoption in numerous research projects [12].

Research by El-laithy et al. aims to integrate the Kinect sensor into an autonomous ground vehicle, the Unmanned Utility Robotic Ground Vehicle (UURGV), to enhance its capabilities. The UURGV can autonomously cut grass and navigate outdoor areas using a laser scanner sensor and GPS. However, GPS navigation is ineffective indoors or near solid concrete structures. They propose integrating the Kinect sensor with other sensors, such as an inertial measurement unit (IMU), to optimize indoor navigation. By utilizing the Kinect's depth camera, the robot can detect approximate distances to objects and navigate around them while also gaining 3D perception [12].

Correa et al. project introduces a perception system for autonomous navigation of mobile surveillance robots in indoor environments. The method comprises two components: a reactive navigation system that uses the Kinect distance sensor to avoid obstacles and an artificial neural network (ANN) trained on Kinect data to identify various environment configurations. By combining reactive and deliberative behaviours, the robot can navigate using a topological map represented as a graph. The system shows promising outcomes regarding autonomous mobile robot navigation, including the ability to operate in dark environments, and its effectiveness was verified using a Pioneer P3-AT robot [13].

The paper by Eric and Jang focuses on using the Kinect depth sensor, a low-cost range sensor, to detect objects and measure their distance, providing an affordable and reliable option for computer vision. The results demonstrate that the Kinect sensor and segmentation techniques can effectively detect objects and accurately measure their distance. This research makes it suitable for obstacle avoidance and other applications that require a vision sensor, not only for unmanned vehicles but also for manned vehicles to alert drivers. Computer vision plays a crucial role in vehicles without human intervention [14].

A common use of the Kinect sensor in VR is full-body tracking. It allows users to see their body movements replicated in the virtual world, enhancing the sense of presence and embodiment. The method can be precious in VR applications focused on physical training, rehabilitation, or social interactions. Additionally, the Kinect sensor's microphone array enables voice recognition and voice commands, allowing users to interact with the VR environment using speech. The system can enhance the usability and hands-free nature of VR experiences.

Clark et al. conducted a study to evaluate and compare the accuracy and consistency of kinematic data collected from a marker-based 3D motion analysis system and the Kinect Sensor V2 across different static and dynamic balance evaluations. The results showed excellent concurrent validity for trunk angle data in active tasks and anterior–posterior range and path length in static balance tasks, indicating the potential of the Kinect Sensor V2 as a reliable and valid tool for assessing specific aspects of balance performance [15].

3 Applications of VR and Kinect Sensor in Biomedical and Health Fields

Virtual reality (VR) has shown significant potential in the biomedical field, offering a range of applications. In these domains, using virtual reality (VR) involves the implementation of computer-generated environments and simulations that deeply engage individuals, aiming to improve medical research, education, diagnostics, healthcare services, treatment, and rehabilitation. By leveraging VR technology, biomedical professionals can explore and interact with virtual representations of anatomical structures, physiological processes, and medical scenarios.

A systematic review methodology was employed to gather relevant literature and projects related to the applications of VR and Kinect sensors in healthcare. Databases such as Google Scholar, IEEE Xplore, and PubMed were searched for articles and studies published between 2013 and 2022. Keywords included "Virtual Reality," "Kinect Sensor," "Healthcare," "Biomedical," "Medical Applications," and related terms. Studies were selected based on relevance to the topic and their contributions to the field.

For example, the paper by Kassem et al. introduces a smart digital medical bed called MedBed, designed to address critical issues in hospitals related to timely nurse intervention and patient independence. MedBed is intended to give patients autonomy and enable them to take necessary actions when nurses are unavailable. The bed incorporates features ranging from basic to highly impactful on the patient's vital status. It allows voice commands from the patient and communicates as part of the Internet of Things (IoT) through a user-friendly smartphone application. A database is included to track activities such as medication and reminders. MedBed can be implemented in medical centers with minimal infrastructure changes [16].

Hesham A. Alabbasi et al. in their research [17], aim to utilize facial emotion recognition and brain activity to detect facial expressions and identify the corresponding brain regions in stroke patients with limited verbal communication. The proposed method involves tracking the patient's face and using the recorded coordinates to classify facial expressions through a neural network in Matlab. The results are displayed on the screen, and while initially focused on stroke patients, the approach can be extended to monitor individuals with conditions like Alzheimer's or dementia. A minimal set of 17 features was used to optimize efficiency to recognize eight emotion expressions. At the same time, future work involves expanding the database to include a more diverse range of individuals for improved recognition.

Lohse et al. reviewed the effectiveness of VR therapy in stroke survivors using custom-built virtual environments (VE) and commercially available gaming systems (CG). Out of the twenty-six studies included, the results showed that VR therapy was significantly more effective than conventional therapy in improving body function and activity outcomes. No significant differences were found between VE and CG interventions for these outcomes. However, participation outcomes were mainly derived from VE studies, indicating moderate improvements in VR rehabilitation compared to conventional therapy [2].

Thomas et al. present a modified smart wheelchair to support individuals with restricted mobility. It is based on a commercially available manual wheelchair but includes additional features such as a stereo depth camera, LIDAR, DC gear motor, joystick, and processors. Users have the flexibility to control the wheelchair manually using a joystick or hands-free through a specially developed application. The wheelchair has a Jetson processor, enabling it to navigate autonomously within indoor environments and reach the desired destination. While initially designed for hospitals, this affordable and lightweight wheelchair has the potential to be used in various indoor settings. The project also provides open-source design files, allowing for replication and accessibility to a broader audience [18].

A study by Ivan Yong-Sing, Lau et al. [19] proposed a knee osteoarthritis severity diagnostics system for gait analysis. The researchers collaborated with Sibu Hospital and KPJ Sibu Specialist Hospital to collect subject data. The study utilized the law of cosine and dot cross product as primary measures to analyze gait parameters of the knee, ankle, and hip. The proposed system successfully captures subject movement using the Microsoft Kinect v2 sensor and demonstrates an analysis algorithm for various gait parameters. Future work includes enhancing the system with machine learning algorithms to determine the severity grade of knee osteoarthritis.

The utilization of Kinect extends to supporting the diagnosis and treatment of Scoliosis [20]. For Alzheimer's disease detection, a method is proposed that utilizes a Kinect V.2 camera and machine learning to evaluate the Timed Up and Go (TUG) test and differentiate individuals with Alzheimer's disease (AD) from healthy controls (HC) [21]. Data on joint positions were gathered from both HC and AD participants, and features were extracted from various TUG subtasks. Significant features were identified through statistical analysis and machine learning that could effectively distinguish AD from HC. This approach demonstrates promise as an accessible and convenient tool for early-stage AD assessment.

As part of a system that enables real-time supervision and monitoring of patients in Intensive Care Units (ICU) within hospital settings, the Kinect sensor is equipped with a range of sensors that track patients' movements, recognize faces and process speech. These sensors do not require physical contact with the patients and instead utilize a Natural User Interface to detect skeletal movements [22].

Limin and Peiyi proposed a gesture recognition method based on LabVIEW and utilizing the 3D somatosensory camera of Kinect for controlling a medical service robot. It tracks human skeleton points, captures real-time human actions, and identifies different body actions on the LabVIEW platform. The Kinect sensor comprises various components such as a primary camera, infrared emitter, infrared depth image camera, rotatable support, and matrix microphone. It captures depth images, colour images, and sound to identify human body movements. The method enables effective human–computer interaction and provides convenience for assistant doctors in completing patient rehabilitation and nursing tasks [23].

In 2022, Amira Gaber et al. developed a system for evaluating facial paralysis (FP), including assessment and classification [24]. The system uses the Kinect V2 sensor to extract real-time facial animation units (FAUs) and employs artificial intelligence and machine learning techniques for classification. A dataset of 375 records from 13 FP patients and 1650 records from 50 control subjects was used to classify seven FP categories, including three severity levels for each side of the face. An ensemble learning classifier based on SVMs was developed to achieve high prediction accuracy. The study demonstrates the effectiveness of using FAUs acquired by the Kinect sensor for classifying FP and highlights the advantages of the developed system over existing grading scales.

Zaid A. Munder and Jiaofei Zhong explore using of a mobile robot and Kinect sensor to develop an intelligent system capable of monitoring and detecting hazardous events such as falls [25]. The Kinect sensor, integrated with the mobile robot, is used to track and detect when a person falls. When a fall is detected, the system sends SMS notifications and makes emergency calls using a mobile phone installed on the robot. The use of depth cameras, such as the Kinect sensor, offers advantages over traditional RGB cameras, providing improved performance, lower costs, and resilience to changes in lighting conditions.

In [26], using Kinect extends to assist blind individuals in navigation by using real-time depth data. The system can detect various environmental patterns, such as obstacles, walls, and stairs. These tasks pose challenges when relying on direct operation by a clinician. However, limitations exist regarding the Kinect sensor's portability and its challenges when capturing depth information in outdoor environments exposed to sunlight or water.

A Microsoft Kinect sensor system has been suggested for exercise control in physiotherapy patients [27]. It adeptly analyzes joint orientations and evaluates muscle group forces, as evidenced by successful experimental outcomes. Moreover, the method holds the potential for exercise control and monitoring applications. The study emphasizes joint range of motion detection and muscle group load analysis, employing the dot product technique for precise angle calculation. However, the system has not been entailed with a 3D virtual instructor, integrating voice commands and visual movements.

Another method proposes a personal coaching system using a Microsoft Kinect Sensor to monitor and ensure the correct execution of physiotherapy exercises at home [28]. The system includes an exercise-detection algorithm, a recognition module, and a user-friendly web interface. The results demonstrate the successful use of the system for remote physiotherapy exercises, particularly valuable during the COVID-19 pandemic. The Kinect Sensor, known for its movement and speech recognition capabilities, tracks joint coordinates and offers static and dynamic exercises. The system shows promise for remote physiotherapy, and future work aims to integrate it into more advanced virtual coaching systems involving social robots and Ambient Assisted Living environments.

An approach included a system that utilizes gesture recognition of upper body limb movements using the Kinect sensor [29]. The system drives a mobile robotic arm as a prototype. It can be extended to trigger various services for elderly and wheelchair users to help them in their daily activities. The Kinect sensor captures 3D skeleton positions, which are processed by the software tool and converted into data for the microcontroller.

Table 1 showcases additional applications of Kinect sensors within the biomedical and healthcare environment.

Several studies have demonstrated the feasibility and effectiveness of Kinect sensors in medical diagnostic tasks. For instance, Sooklal et al. (2014) explored the detection of tremors using Kinect, providing a potential non-invasive tool for diagnosing conditions like Parkinson's disease [6]. Similarly, Stone et al. (2014) developed a Kinect-based system that generates health alerts from gait measurements, enabling early detection of health changes in gait patterns [31]. These applications showcase the potential of Kinect technology to aid in the assessment and monitoring of various medical conditions.

In the context of Parkinson's disease, Amini Maghsoud Bigy et al. (2015) developed a real-time monitoring system using Kinect to detect Freezing of Gait, tremor, and fall incidents [41]. Their work highlights the potential of Kinect sensors to track joint positions and movements for symptom detection and monitoring. Ren et al. (2019) introduced a multivariate analysis method using Kinect data for Parkinson's disease assessment, demonstrating accuracy in classifying different impairment levels [40]. These studies exemplify the utility of Kinect sensors in advancing the field of medical diagnostics, enabling non-invasive and remote monitoring of various symptoms and conditions.

Kinect technology has shown promise in the realm of rehabilitation and physiotherapy, providing innovative solutions for exercise guidance and assessment. Vogiatzaki et al. (2014) developed a game-based tele-rehabilitation system using Kinect, aiming to enhance stroke patient rehabilitation remotely [32]. Similarly, Saratean et al. (2020) developed a remote physiotherapy application utilizing Kinect, which enabled exercise detection and guidance for patients while allowing physiotherapists to track progress through a web interface [28]. These studies emphasize

Table 1 Applications of Kinect sensor within biomedical and healthcare

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Healthcare	2018	Gavrilova et al. [30]	Explore applications of Kinect sensors for gesture and activity recognition in various contexts	Utilized Kinect's capabilities to capture gesture and activity data	Addressed the potential of Kinect sensors for various applications in healthcare, consumer electronics, and cognitive systems	Individuals performing gestures and activities	Demonstrated Kinect's potential in applications ranging from smart homes to biometric surveillance	Acknowledged challenges of context-based recognition and data privacy
Medical diagnostic	2014	Sooklal et al. [6]	Detect tremors using Kinect	Simulation of tremors, Kinect data capture	Detect Parkinsonian, postural, voice tremors	Accuracy in detecting head tremors, sensitivity to background movement	Kinect sensor, tremors	Potential for home monitoring and therapy
Medical diagnostic	2014	Stone et al. [31]	Generate health alerts from gait measurements	Kinect-based gait measurement system	Early detection of health changes in gait patterns	Modeling uncertainty in gait parameter estimates	Gait measurement system	Alerts for potential health issues
Rehabilitation	2014	Vogiatzaki et al. [32]	Develop game-based tele-rehabilitation system	Kinect, virtual reality, cloud-based system	Game-based rehabilitation for stroke patients	Remote exercise monitoring, bio-feedback	Tele-rehabilitation system	Enhance stroke patient rehabilitation

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Medical diagnostic, rehabilitation	2015	Pineda-Lopez et al. [33]	Develop gait analysis system using Kinect	Kinect sensor, database system	Gait analysis and visualization	Diagnosing walking problems, rehabilitation	Human body movement analysis	Gait cycle classification
Rehabilitation	2016	Pathirana et al. [34]	Develop real-time tele-rehabilitation system	Kinect, multiple devices, Kalman filter	Accurate joint position estimation	Robust bio-kinematic tracking	Tele-rehabilitation system	Improved movement tracking
Medical diagnostic	2017	Tanaka and Sogabe [35]	Measure and classify leg shapes	Kinect sensor, algorithm	Automated leg shape measurement	Classify genu valgum and genu varum	Leg shapes, Kinect sensor	Accurate leg shape classification
Medical diagnostic	2013	Shao et al. [36]	Introduce Kinect-like sensors for computer vision applications	Reviewed applications of Kinect-like sensors for computer vision	Explored the potential of Kinect-like sensors in computer vision applications	RGB-D sensor applications in computer vision	Highlighted advancements in object recognition, 3D mapping, and scene classification	Addressed challenges in depth computation and fusion
Medical diagnostic	2017	Jawaid and Qureshi [3]	Review of Kinect-based medical imaging applications	Explored applications of Kinect for medical imaging tasks	Highlighted Kinect's use in medical imaging for diagnostics and treatments	Medical imaging using Kinect	Demonstrated Kinect's applications in medical diagnostics	Addressed challenges of noise, accuracy, and sensor fusion

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Medical diagnostic	2018	Eltoukhy et al. [37]	Validate Kinect v2 sensor for assessing balance in both young and elderly populations	Utilized Kinect v2 to capture balance-related data during static and dynamic tasks	Addressed limitations in assessing balance accurately and conveniently	Young and elderly participants performing balance tasks	Kinect v2 provided valid measurements of balance-related parameters for both age groups	Limitations included small sample size and challenges in temporal variations
Medical diagnostic	2019	Saraguro et al. [38]	Develop a system to analyze hand movements in PD patients using Kinect	Utilized Kinect V2 sensor, tracked hand movements for PD evaluation	Provided non-invasive tool for evaluating PD progression via finger tapping tests	Hand movements of PD patients	Detected lower tapping velocity in upper right extremities of PD patients	Variation in medication status, sensitivity to disease severity
Medical diagnostic	2019	Dehbandi et al. [39]	Explore the feasibility of using Kinect 2 data for quantifying upper limb behavior in motor disorders	Developed a method to quantify joint motion data using Kinect 2	Addressed limitations in accurately capturing motor symptoms and movement patterns in motor disorders	Participants with and without motor disorders performing sit-to-stand-to-sit motion	Proposed method showed exceptional classification performance for distinguishing healthy and motor disorder participants	Challenges included computational demands of the method and broader assessment of motor symptoms

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Training	2017	Limin and Peiyi [23]	Develop a gesture recognition method for controlling a medical service robot using Kinect	Kinect technology, LabVIEW software	Enhancing human–computer interaction in medical service robots	Medical service robot	Successful human–computer interaction for controlling medical service robots in healthcare settings	Acknowledges limitations of Kinect positioning and potential accuracy issues due to environmental factors
Medical diagnostic	2019	Ren et al. [40]	Introduce a multivariate analysis method using Kinect data for Parkinson's disease assessment	Developed a method to analyze joint motion data using Kinect for Parkinson's disease assessment	Addressed limitations in accurately capturing motor symptoms in Parkinson's disease	Healthy participants and Parkinson's disease patients performing sit-to-stand-to-sit motion	Proposed method demonstrated accuracy in classifying Parkinson's disease impairment levels	Challenges included computational demands and limited assessment of motor symptoms

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Monitoring, medical diagnostic	2015	Amini Maghsoud Bigy et al. [41]	Develop a Kinect-based system for real-time monitoring and detection of Freezing of Gait, tremor, and fall incidents in Parkinson's disease patients	Utilized Kinect sensor to track joint positions and movements for symptom detection	Addressed challenges of detecting critical incidents in Parkinson's disease patients	Parkinson's disease patients exhibiting various symptoms	Demonstrated Kinect's potential for detecting FOG, tremor, and falls with promising accuracy	Limitations included simulated subjects and potential tracking errors
Physiotherapy	2017	Cubukcu and Yuzgec [42]	Develop a Kinect-based physiotherapy application for patients with shoulder joint, muscle, and tendon damage	Created a physiotherapy application using Kinect for exercise guidance and assessment	Addressed difficulties in accessing physiotherapy centers and performing exercises correctly	Patients with shoulder joint, muscle, and tendon damage	Demonstrated the potential of Kinect-based application for remote physiotherapy guidance	Limitations included focusing on specific conditions and lack of interactive communication
Physiotherapy	2020	Saratean et al. [28]	Develop a system for remote physiotherapy using Kinect	Utilized Kinect Sensor for exercise detection, web interface for physiotherapists	Supported remote physiotherapy through exercise guidance and tracking	Physiotherapy exercises	Detected exercise correctness and guided patients remotely	Limitation in tracking obscured joints, Kinect's field of view limitation

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Physiotherapy	2020	Huang et al. [43]	Develop a Kinect-based self-help training system for nursing students to learn patient transfer skills	Utilized Kinect RGB-D sensors to measure trainee and patient postures for skill evaluation	Addressed the limitations of traditional nursing education for patient transfer skills	Nursing students learning patient transfer skills	Demonstrated accuracy and effectiveness of the system for improving patient transfer skills	Addressed tracking errors and potential challenges in evaluation
Rehabilitation	2014	Gauthier and Cretu [44]	Develop a Kinect-based system for monitoring and assessing exercise performance in home-based settings	Utilized Kinect to track joint movements and quantify exercise performance	Addressed limitations in monitoring exercise performance and adherence in home environments	Individuals performing physical exercise at home	Demonstrated the feasibility of using Kinect for quantifying exercise movements and providing feedback	Limitations included simplified joint model and potential measurement errors
Rehabilitation	2015	Lai et al. [45]	Develop a Kinect-based system for virtual rehabilitation to train balance in stroke patients	Utilized Kinect V1 to create a virtual rehabilitation system	Addressed limitations of in-person rehabilitation for stroke patients by providing a home-based training solution	Stroke patients performing balance training exercises	Significant improvements in balance-related parameters for stroke patients using the Kinect-based system	Challenges included further exploration of exercises and ensuring consistent participation

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Medical education	2015	Pauly et al. [46]	Improve surgical scene understanding	Augmented reality using Kinect and X-ray data fusion	Enhance spatial understanding in orthopedic surgery	Augmented reality setup	Improved surgical scene understanding, depth perception enhancement	Challenges in object recognition using color and depth cues
Rehabilitation	2017	Park et al. [47]	Assess VR training effects on motor recovery	Virtual reality training with Xbox Kinect	Improve motor function and recovery in stroke survivors	Stroke survivors	VR training improved motor function, efficient instrument movement	Discrepancy in intervention time, Kinect recognition errors
Medical education	2018	Feng et al. [48]	Evaluate Virtual Pointer in laparoscopic training	Virtual Pointer system using Kinect for guidance	Enhance professional vision in laparoscopic surgical training	Surgical trainees	Virtual Pointer improved perception and economy of movement	No significant reduction in errors or time to completion
Medical services	2014	Kim et al. [49]	Compare Kinect hand tracking to mechanical control	Kinect hand tracking technology for surgical robots	Explore feasibility of Kinect-based control for surgical robots	Experienced surgeons	Kinect hand tracking is promising but needs improvement	Latency and static noise affecting performance
Rehabilitation, monitoring	2014	Saiyi Li et al. [50]	Improve Kinect-based rehabilitation monitoring	Multi-Kinect fusion for joint position measurement	Enhance accuracy of joint position measurement in rehab monitoring	Rehabilitation patients	Improved joint position measurement accuracy	Noise in Kinect data, limited dataset size

(continued)

Table 1 (continued)

Application fields	Year	Authors	Purpose	Method Used	Problems Solved	Object	Results	Weaknesses
Medical services	2017	Xiao et al. [51]	Develop Kinect-based navigation system	Optical navigation using Kinect camera	Enhance accuracy of needle insertion in abdominal interventions	Phantom and animal experiments	Accurate needle placement, better accuracy with Kinect V2	Complexity of workflow, need for respiratory compensation
Medical education	2022	Fuchs et al. [52]	Develop evaluation system for endoscopic training	Multimodal feature combination using Kinect and EMG	Evaluate learning benefits of stereoscopic views in training	Surgical trainees	Validated simulator-independent endoscopic skill assessment	Small dataset size, need for more extensive training

the potential of Kinect-based systems to support rehabilitation and physiotherapy efforts by offering remote guidance and monitoring capabilities.

Lai et al. (2015) developed a Kinect-based virtual rehabilitation system to train balance in stroke patients, providing an alternative to in-person rehabilitation [45]. The findings suggest significant improvements in balance-related parameters for stroke patients using the Kinect-based system. Additionally, Cubukcu and Yuzgec (2017) created a Kinect-based physiotherapy application for patients with shoulder joint, muscle, and tendon damage, offering exercise guidance and assessment outside of traditional healthcare settings [42]. These studies highlight the potential of Kinect technology to revolutionize the field of rehabilitation, making exercise guidance and assessment more accessible and convenient for patients.

In the realm of surgical training and education, Kinect technology has been explored to enhance surgical skills and professional vision. Feng et al. (2018) evaluated the effectiveness of the Virtual Pointer system in improving laparoscopic surgical training by using Kinect for visual guidance [48]. The results indicated improved perception and economy of movement, enhancing trainees' adoption of professional vision. Moreover, Kim et al. (2014) investigated the feasibility of using Kinect-based hand tracking technology for controlling surgical robots, showcasing its potential to revolutionize surgical control methods [49]. These studies illustrate the potential of Kinect technology to enhance surgical training and control systems, offering innovative solutions to improve skill development and performance.

These applications above show that VR has positively impacted the biomedical field and healthcare environment. The application of VR will continue to develop and experience further improvements to help improve diagnosis, therapy, health education, and many more.

3.1 Challenges and Opportunities in the Use of VR and Kinect Sensor

While the integration of VR and Kinect technology holds promise in healthcare, there are challenges to consider. Accuracy [41], potential tracking errors [3, 44], and computational demands [40] are among the limitations identified in various studies. Additionally, the adoption of these technologies in clinical settings requires careful consideration of patient safety, data privacy [30], and effective integration into existing healthcare workflow.

The algorithm's performance might vary based on individual characteristics, and further refinements and real-time testing are needed to validate its reliability. The study also acknowledged the possibility of false positives or missed alerts and emphasized the importance of parameter tuning by clinicians [31, 53].

The accurate and reliable capture of data stands as a central challenge in applications reliant on both Virtual Reality (VR) and Kinect-based technology. The studies underscore the critical demand for precision in tracking movements, particularly within clinical contexts where precise data is imperative for diagnostic and therapeutic purposes. The calibration and setup of Kinect sensors represent essential factors in attaining accurate data [54]. Ensuring the precise positioning and orientation of these sensors can prove challenging, particularly when dealing with home-based environments. Additionally, the presence of environmental variables, occlusions, and noise within depth data [6] can significantly impact the accuracy of tracking and recognition algorithms. The resolution of these issues is of paramount importance to establish dependable and consistent outcomes.

The development of robust algorithms to facilitate gesture recognition, movement tracking, and pose estimation [53] introduces a complex undertaking. This necessitates careful consideration of numerous factors, including the selection of appropriate machine learning models and feature extraction techniques. Furthermore, the diverse nature of human anatomy and movements across individuals accentuates the need for algorithms and systems that can adeptly adapt to accommodate these differences. This ensures the technology's effectiveness across a wide spectrum of users.

Real-time processing [32], especially in applications like tele-rehabilitation and human–robot interaction, introduces challenges due to the requisite low latency and immediate feedback. The integration of VR and Kinect-based systems into established clinical practices mandates validation, regulatory compliance, and alignment with healthcare standards. Clinicians seek assurance regarding the technology's precision, safety, and efficacy, thereby emphasizing the need for comprehensive validation and adherence to industry regulations.

While using virtual reality (VR) and the Kinect sensor has challenges in various fields, it also brings numerous opportunities. VR and Kinect technologies present a remarkable avenue for remote monitoring and rehabilitation, enabling patients to seamlessly engage in therapy from the comfort of their homes. This holds the potential to ameliorate patient compliance and alleviate the strain on healthcare facilities. Integrating gamification and interactive exercises into rehabilitation programs imparts an engaging and motivating dimension. The immersive qualities of VR, coupled with the natural interaction facilitated by Kinect sensors, synergistically contribute to heightened patient adherence and participation rates.

Beyond patient engagement, the amalgamation of VR and Kinect-based systems yields a trove of movement data that can be systematically analyzed to yield insights into patient progress, movement patterns, and avenues for potential enhancement. This data-centric approach paves the way for personalized rehabilitation regimens that cater to individual needs.

A distinctive advantage of Kinect sensors lies in their cost-effectiveness as a depth-sensing solution, particularly when juxtaposed with more intricate motion capture systems. The affordability of Kinect sensors extends opportunities for broader adoption, particularly in settings with resource constraints. The meticulous tracking and detailed movement analysis facilitated by Kinect sensors hold profound diagnostic potential for identifying movement disorders and evaluating the efficacy of treatments. Moreover, VR-based diagnostic tools, enriched by Kinect data, proffer clinicians with invaluable insights to inform their decision-making.

VR and Kinect systems exhibit remarkable adaptability, allowing interventions to be tailored to individual progress and capabilities. This adaptiveness, in conjunction with the synergy between VR and Kinect, extends beyond rehabilitation to enrich human–robot interaction. The fusion of these technologies empowers robots to comprehend and respond to human gestures and movements with heightened intuition, fostering a more seamless interaction between humans and machines.

The collective studies underscore the strides made in the field, yet concurrently emphasize the expansive realm for further research and innovation. The path forward beckons the development of novel algorithms, the refinement of existing technologies, and the exploration of untapped applications. As these technologies mature, the marriage of VR and Kinect is poised to revolutionize healthcare, offering solutions that transcend physical boundaries and cater to individual needs with unprecedented precision.

While the studies presented valuable insights, there are several limitations to consider. First, the reviewed studies relied on relatively small sample sizes, limiting the generalizability of the findings. The studies predominantly focused on specific medical conditions, potentially excluding broader applications. Furthermore, the challenges related to VR and Kinect technology, such as hardware limitations and user comfort, were not always extensively explored within the reviewed studies.

4 Conclusion

Virtual reality (VR) has significantly changed various industries, including biomedical and health. By immersing individuals in computer-generated environments, VR offers interactive and immersive experiences, and its applications extend beyond being a medium or advanced user interface. VR has practical solutions to real-world challenges, and its effectiveness relies on immersion, interaction, and imagination. The history of VR spans over 40 years, with significant advancements in hardware and software components. The Kinect sensor, initially developed for gaming, has found applications in biomedical and health fields, such as diagnostic tasks, monitoring of various medical conditions, rehabilitation and physiotherapy, surgical training and education. While challenges exist, VR and the Kinect sensor provide opportunities for personalized interventions, remote healthcare delivery, training, collaboration, and improved patient engagement. As technology evolves, the potential of VR and the Kinect sensor in healthcare is expected to grow, with a focus on managing costs, enhancing hardware capabilities, ensuring data security, and refining user experiences.

References

1. Pensieri C, Pennacchini M (2016) Virtual reality in medicine. https://doi.org/10.1007/978-3-319-22041-3_14
2. Lohse KR, Hilderman CGE, Cheung KL, Tatla S, Van der Loos HFM (2014) Virtual reality therapy for adults post-stroke: a systematic review and meta-analysis exploring virtual environments and commercial games in therapy. PLoS ONE 9:e93318. https://doi.org/10.1371/journal.pone.0093318
3. Jawaid I, Qureshi JK (2017) Advancements in medical imaging through Kinect: a review. In: 2017 international symposium on wireless systems and networks (ISWSN). IEEE, pp 1–5. https://doi.org/10.1109/ISWSN.2017.8250032
4. Dargar S, Nunno A, Sankaranarayanan G, De S (2013) Microsoft Kinect based head tracking for life size collaborative surgical simulation environments (LS-CollaSSLE). Stud Health Technol Inform 184:109–113
5. Palter VN, Grantcharov TP (2010) Virtual reality in surgical skills training. Surg Clin North Am 90:605–617. https://doi.org/10.1016/j.suc.2010.02.005
6. Sooklal S, Mohan P, Teelucksingh S (2014) Using the Kinect for detecting tremors: challenges and opportunities. In: IEEE-EMBS international conference on biomedical and health informatics (BHI). IEEE, pp 768–771. https://doi.org/10.1109/BHI.2014.6864477
7. Suarez J, Murphy RR (2012) Hand gesture recognition with depth images: a review. In: 2012 IEEE RO-MAN: the 21st IEEE international symposium on robot and human interactive communication. IEEE, pp 411–417. https://doi.org/10.1109/ROMAN.2012.6343787
8. Burdea GC, Coiffet P (2003) Virtual reality technology. Wiley
9. Burdea GC (1999) Invited review: the synergy between virtual reality and robotics. IEEE Trans Robot Autom 15:400–410. https://doi.org/10.1109/70.768174
10. Zhang Z (2012) Microsoft Kinect sensor and its effect. IEEE Multimed 19:4–10. https://doi.org/10.1109/MMUL.2012.24
11. Yang L, Zhang L, Dong H, Alelaiwi A, El Saddik A (2015) Evaluating and improving the depth accuracy of Kinect for Windows v2. IEEE Sens J 15:4275–4285. https://doi.org/10.1109/JSEN.2015.2416651
12. El-laithy RA, Huang J, Yeh M (2012) Study on the use of Microsoft Kinect for robotics applications. In: Proceedings of the 2012 IEEE/ION position, location and navigation symposium. IEEE, pp 1280–1288. https://doi.org/10.1109/PLANS.2012.6236985
13. Correa DSO, Sciotti DF, Prado MG, Sales DO, Wolf DF, Osório FS (2012) Mobile robots navigation in indoor environments using Kinect sensor. In: Proceedings - 2012 2nd Brazilian conference on critical embedded systems, CBSEC 2012, pp 36–41. https://doi.org/10.1109/CBSEC.2012.18
14. Eric N, Jang J-W (2017) Kinect depth sensor for computer vision applications in autonomous vehicles. In: 2017 ninth international conference on ubiquitous and future networks (ICUFN). IEEE, pp 531–535. https://doi.org/10.1109/ICUFN.2017.7993842
15. Clark RA, Pua Y-H, Oliveira CC, Bower KJ, Thilarajah S, McGaw R, Hasanki K, Mentiplay BF (2015) Reliability and concurrent validity of the Microsoft Xbox One Kinect for assessment of standing balance and postural control. Gait Posture 42:210–213. https://doi.org/10.1016/j.gaitpost.2015.03.005
16. Kassem A, Hamad M, El Moucary C, Nawfal E, Aoun A (2017) MedBed: smart medical bed. In: 2017 Fourth international conference on advances in biomedical engineering (ICABME). IEEE, pp 1–4. https://doi.org/10.1109/ICABME.2017.8167544
17. Alabbasi HA, Moldoveanu F, Moldoveanu A, Shhedi Z (2015) Facial emotion expressions recognition with brain activites using Kinect sensor V2. Int Res J Eng Technol
18. Sola-Thomas E, Baser Sarker MA, Caracciolo MV, Casciotti O, Lloyd CD, Imtiaz MH (2021) Design of a low-cost, lightweight smart wheelchair. In: 2021 IEEE microelectronics design and test symposium, MDTS 2021. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/MDTS52103.2021.9476093

19. Lau IY-S, Chua T-T, Lee WX-P, Wong C-W, Toh T-H, Ting H-Y (2020) Kinect-based knee osteoarthritis gait analysis system. In: 2020 IEEE 2nd international conference on artificial intelligence in engineering and technology (IICAIET). IEEE, pp 1–6. https://doi.org/10.1109/IICAIET49801.2020.9257860
20. Cukovic S, Petruse RE, Meixner G, Buchweitz L (2020) Supporting diagnosis and treatment of scoliosis: using augmented reality to calculate 3D spine models in real-time - ARScoliosis. In: 2020 IEEE international conference on bioinformatics and biomedicine (BIBM). IEEE, pp 1926–1931. https://doi.org/10.1109/BIBM49941.2020.9313200
21. Seifallahi M, Mehraban AH, Galvin JE, Ghoraani B (2022) Alzheimer's disease detection using comprehensive analysis of timed up and go test via Kinect vol 2 Camera and machine learning. IEEE Trans Neural Syst Rehabil Eng 30:1589–1600. https://doi.org/10.1109/TNSRE.2022.3181252
22. Shehabat IM, Al-Hussein N (2018) Deploying internet of things in healthcare: benefits, requirements, challenges and applications. J Commun 574–580. https://doi.org/10.12720/jcm.13.10.574-580
23. Limin M, Peiyi Z (2017) The medical service robot interaction based on Kinect. In: 2017 IEEE international conference on intelligent techniques in control, optimization and signal processing (INCOS). IEEE, pp 1–7. https://doi.org/10.1109/ITCOSP.2017.8303077
24. Gaber A, Taher MF, Wahed MA, Shalaby NM, Gaber S (2022) Classification of facial paralysis based on machine learning techniques. Biomed Eng Online 21:65. https://doi.org/10.1186/s12938-022-01036-0
25. Mundher ZA, Jiaofei Z (2014) A real-time fall detection system in elderly care using mobile robot and Kinect sensor. Int J Mater Mech Manuf 2:133–138. https://doi.org/10.7763/IJMMM.2014.V2.115
26. Filipe V, Fernandes F, Fernandes H, Sousa A, Paredes H, Barroso J (2012) Blind navigation support system based on Microsoft Kinect. Procedia Comput Sci 14:94–101. https://doi.org/10.1016/j.procs.2012.10.011
27. Topuz B, Ozuag E, Akbulut O (2016) Kinect sensor based physiotherapy management. In: 2016 24th signal processing and communication application conference (SIU). IEEE, pp 2209–2212. https://doi.org/10.1109/SIU.2016.7496213
28. Saratean T, Antal M, Pop C, Cioara T, Anghel I, Salomie I (2020) A physiotheraphy coaching system based on Kinect sensor. In: 2020 IEEE 16th international conference on intelligent computer communication and processing (ICCP). IEEE, pp 535–540. https://doi.org/10.1109/ICCP51029.2020.9266178
29. Ababneh M, Shaban H, AlShalabe D, Khader D, Mahameed H, AlQudimat M (2018) Gesture controlled mobile robotic arm for elderly and wheelchair people assistance using Kinect sensor. In: 2018 15th international multi-conference on systems, signals and devices (SSD). IEEE, pp 636–641. https://doi.org/10.1109/SSD.2018.8570547
30. Gavrilova ML, Wang Y, Ahmed F, Polash Paul P (2018) Kinect sensor gesture and activity recognition: new applications for consumer cognitive systems. IEEE Consum Electron Mag 7:88–94. https://doi.org/10.1109/MCE.2017.2755498
31. Stone EE, Skubic M, Back J (2014) Automated health alerts from Kinect-based in-home gait measurements. In: 2014 36th annual international conference of the IEEE engineering in medicine and biology society. IEEE, pp 2961–2964. https://doi.org/10.1109/EMBC.2014.6944244
32. Vogiatzaki E, Gravezas Y, Dalezios N, Biswas D, Cranny A, Ortmann S, Langendorfer P, Lamprinos I, Giannakopoulou G, Achner J, Klemke J, Jost H (2014) Telemedicine system for game-based rehabilitation of stroke patients in the FP7-"StrokeBack" project. In: 2014 European conference on networks and communications (EuCNC). IEEE, pp 1–5. https://doi.org/10.1109/EuCNC.2014.6882688
33. Pineda-Lopez FM, Flores CMJ, Ortiz VGJ, Mosquera YWA (2015) Prototype for the analysis of human body movement with Kinect sensor. In: 2015 20th symposium on signal processing, images and computer vision (STSIVA). IEEE, pp 1–7. https://doi.org/10.1109/STSIVA.2015.7330410

34. Pathirana PN, Li S, Trinh HM, Seneviratne A (2016) Robust real-time bio-kinematic movement tracking using multiple Kinects for tele-rehabilitation. IEEE Trans Industr Electron 63:1822–1833. https://doi.org/10.1109/TIE.2015.2497662
35. Tanaka M, Sogabe A (2017) A measuring system of the legs shape by using the Kinect sensor. In: 2017 56th annual conference of the society of instrument and control engineers of Japan (SICE). IEEE, pp 106–109. https://doi.org/10.23919/SICE.2017.8105558
36. Shao L, Han J, Xu D, Shotton J (2013) Computer vision for RGB-D sensors: Kinect and its applications [special issue intro]. IEEE Trans Cybern 43:1314–1317. https://doi.org/10.1109/TCYB.2013.2276144
37. Eltoukhy MA, Kuenze C, Oh J, Signorile JF (2018) Validation of static and dynamic balance assessment using Microsoft Kinect for young and elderly populations. IEEE J Biomed Health Inform 22:147–153. https://doi.org/10.1109/JBHI.2017.2686330
38. Saraguro W, Barzallo B, Guillermo J, Garcia-Cedeno A, Soto A, Rivas D, Clotet R, Huerta M (2019) Analysis of hand movements in patients with Parkinson's disease using Kinect. In: 2019 IEEE international conference on e-health networking, application and services (HealthCom). IEEE, pp 1–6. https://doi.org/10.1109/HealthCom46333.2019.9009589
39. Dehbandi B, Barachant A, Harary D, Long JD, Tsagaris KZ, Bumanlag SJ, He V, Putrino D (2017) Using data from the Microsoft Kinect 2 to quantify upper limb behavior: a feasibility study. IEEE J Biomed Health Inform 21:1386–1392. https://doi.org/10.1109/JBHI.2016.2606240
40. Ren P, Bosch Bayard JF, Dong L, Chen J, Mao L, Ma D, Sanchez MA, Morejon DM, Bringas ML, Yao D, Jahanshahi M, Valdes-Sosa PA (2020) Multivariate analysis of joint motion data by Kinect: application to Parkinson's disease. IEEE Trans Neural Syst Rehabil Eng 28:181–190. https://doi.org/10.1109/TNSRE.2019.2953707
41. Amini Maghsoud Bigy A, Banitsas K, Badii A, Cosmas J (2015) Recognition of postures and Freezing of Gait in Parkinson's disease patients using Microsoft Kinect sensor. In: 2015 7th international IEEE/EMBS conference on neural engineering (NER). IEEE, pp 731–734. https://doi.org/10.1109/NER.2015.7146727
42. Cubukcu B, Yuzgec U (2017) A physiotherapy application with MS Kinect for patients with shoulder joint, muscle and tendon damage. In: 2017 9th international conference on computational intelligence and communication networks (CICN). IEEE, pp 225–228. https://doi.org/10.1109/CICN.2017.8319390
43. Huang Z, Nagata A, Kanai-Pak M, Maeda J, Kitajima Y, Nakamura M, Aida K, Kuwahara N, Ogata T, Ota J (2014) Self-help training system for nursing students to learn patient transfer skills. IEEE Trans Learn Technol 7:319–332. https://doi.org/10.1109/TLT.2014.2331252
44. Gauthier S, Cretu A-M (2014) Human movement quantification using Kinect for in-home physical exercise monitoring. In: 2014 IEEE international conference on computational intelligence and virtual environments for measurement systems and applications (CIVEMSA). IEEE, pp 6–11. https://doi.org/10.1109/CIVEMSA.2014.6841430
45. Lai C-L, Huang Y-L, Liao T-K, Tseng C-M, Chen Y-F, Erdenetsogt D (2015) A Microsoft Kinect-based virtual rehabilitation system to train balance ability for stroke patients. In: 2015 international conference on cyberworlds (CW). IEEE, pp 54–60. https://doi.org/10.1109/CW.2015.44
46. Pauly O, Diotte B, Fallavollita P, Weidert S, Euler E, Navab N (2015) Machine learning-based augmented reality for improved surgical scene understanding. Comput Med Imaging Graph 41:55–60. https://doi.org/10.1016/j.compmedimag.2014.06.007
47. Park D-S, Lee D-G, Lee K, Lee G (2017) Effects of virtual reality training using Xbox Kinect on motor function in stroke survivors: a preliminary study. J Stroke Cerebrovasc Dis 26:2313–2319. https://doi.org/10.1016/j.jstrokecerebrovasdis.2017.05.019
48. Feng Y, McGowan H, Semsar A, Zahiri HR, George IM, Turner T, Park A, Kleinsmith A, Mentis HM (2018) A virtual pointer to support the adoption of professional vision in laparoscopic training. Int J Comput Assist Radiol Surg 13:1463–1472. https://doi.org/10.1007/s11548-018-1792-9

49. Kim Y, Leonard S, Shademan A, Krieger A, Kim PCW (2014) Kinect technology for hand tracking control of surgical robots: technical and surgical skill comparison to current robotic masters. Surg Endosc 28:1993–2000. https://doi.org/10.1007/s00464-013-3383-8
50. Li S, Pathirana PN, Caelli T (2014) Multi-Kinect skeleton fusion for physical rehabilitation monitoring. In: 2014 36th annual international conference of the IEEE engineering in medicine and biology society. IEEE, pp 5060–5063. https://doi.org/10.1109/EMBC.2014.6944762
51. Xiao D, Luo H, Jia F, Zhang Y, Li Y, Guo X, Cai W, Fang C, Fan Y, Zheng H, Hu Q (2016) A Kinect^{TM} camera based navigation system for percutaneous abdominal puncture. Phys Med Biol 61:5687–5705. https://doi.org/10.1088/0031-9155/61/15/5687
52. Fuchs R, Van Praet KM, Bieck R, Kempfert J, Holzhey D, Kofler M, Borger MA, Jacobs S, Falk V, Neumuth T (2022) A system for real-time multivariate feature combination of endoscopic mitral valve simulator training data. Int J Comput Assist Radiol Surg 17:1619–1631. https://doi.org/10.1007/s11548-022-02588-1
53. Tellaeche A, Maurtua I (2014) 6DOF pose estimation of objects for robotic manipulation. A review of different options. In: Proceedings of the 2014 IEEE emerging technology and factory automation (ETFA). IEEE, pp 1–8. https://doi.org/10.1109/ETFA.2014.7005077
54. Bt Ismail NH, Basah SNB (2015) The applications of Microsoft Kinect for human motion capture and analysis : a review. In: 2015 2nd international conference on biomedical engineering (ICoBE). IEEE, pp 1–4. https://doi.org/10.1109/ICoBE.2015.7235894