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Article

A New Augmented Reality System for Calculating Social Distancing Between Children at School

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Abstract: Social distancing is one of the most important ways to prevent many diseases, especially the respiratory system, where the latest internationally spread is coronavirus disease, and it will not be the last. The spreading of this pandemic has become a major threat to human life, especially to the elderly and people suffering from chronic diseases. During the Corona pandemic, medical authorities were keen to control the spread through social distancing and monitoring it in markets, universities, and schools. This monitoring was mostly used to estimate the distance with the naked eye and interfere with estimating the distance on the observer only. In this study, a computer application was designed to monitor social distancing in closed areas, especially in schools and kindergartens, using a fast, effective and unobtrusive technique for children. In addition to this system, we use augmented reality to help to determine the location of violation of social distancing. This system was tested, and the results were accurate exceeding 98.5%.

Keywords: augmented reality (AR); social distancing; Microsoft Kinect; coronavirus disease (COVID-19); unity

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1. Introduction

The coronavirus disease (COVID-19) was causing chaos in all parts of the world. It is affecting every aspect of life, including health, culture, economy, and tourism. It led to many people who have died all over the world [1,2]. All countries were forced to close entirely and put people under compulsory quarantine in their homes. This quarantine caused significant economic losses and greatly affected the psychological state of people [3,4]. All governments directed their citizens to maintain social distancing to limit the spread of the disease [5].

Social distancing is keeping a distance of at least 1.5 m between people to reduce the risk of infection when coughing, sneezing, or talking [6]. Medical authorities were keen on social distancing and monitoring it in markets, universities, and schools, and this monitoring was mostly used to look with the naked eye and interfere in estimating the distance on the observer, and later new systems appeared that using smart technologies such as using wearable smart tags or mobile application-based [7]. In this study, appropriate technology was used to measure social distancing and employ Augmented Reality (AR) to help to determine the location of the violation of social distancing because it does not depend on the naked eye or on wearable sensors or applications on the phone that a person may stop at any time, In addition, most of this new technology is not suitable for children.

AR has been defined as a digital object added to the physical environment. Thus, we will have a new world consisting of physical components and virtual components that can be interacted with [8]. To explain the difference between the terms Virtual Reality (VR) and augmented reality Figure 1 shows two sides of a line the real and virtual environments, Mixed Reality refers to space in between them. In contrast, AR refers to a space closest to the real environment, and VR refers to the space on the other side. AR and VR applications spanned many areas like education, medicine, tourism, entertainment, and marketing [9,10]. In the world of technology, VR is more common and similar to AR technology. VR is the user's transition to reality completely different from the reality in front of him, and the visual field becomes virtual reality only. Furthermore, AR technology uses the real world surrounding the user and adds to it (enhances it) with images or texts according to the application used [11,12].

AR is a digital technology that enables users to interact with virtual objects using a number of techniques [13,14]. The primary aim of this study is to preserve human health from COVID-19 by maintaining social distancing using different and new techniques such as AR.

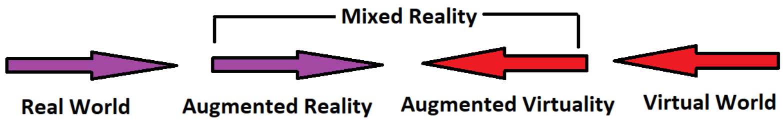

Figure 1. Reality-Virtuality continuum.

2. Related Works

From the beginning of the Corona pandemic to this time, few research studies related to augmented reality have appeared to meet the challenges related to COVID-19. Most of the research was about the medical field (e.g., [15–17]) in terms of employing AR in conducting surgeries, and the studies revolved around the educational area (e.g., [18–20]) in terms of improving the distance learning environment to deliver the information is clear to students.

This section reviews previous work on AR and COVID-19. Table 1 summarizes the AR systems with COVID-19 in different sectors, the most important of which are medical and educational. Each one of the studies aims to address the challenges of COVID-19. In the following overview of the related literature, some of these frameworks' most important features are mentioned.

AR Tracking Techniques

In AR, a variety of tracking techniques are used. These techniques can be ultrasound, magnetic, immobile, automated, or vision based. Since these approaches consider extracting features from images to be enhanced, the outcomes of enhancement are more accurate when using vision-based procedures [21]. In AR, two kinds of tracks can be used:

Marker-less tracking, which entails looking at normal geometry or characteristics. The critical drawback of this approach is that it requires early offline calibration or consideration of participant experiences [22]. It has a high computational cost as well.

Marker-based tracking is an extremely powerful tool for increasing robustness while reducing computing requirements [22,23]. Markers can be easily inserted and removed from the real world [24]. The key drawback of this approach is that it demands continual upkeep [22].

HoloLens glasses are designed by Microsoft, which are smart glasses that contain several sensors to track the movement of the head, a deep-sensing camera to capture three-dimensional information, a graphics processing unit, sound sensors, and a CPU as all of these elements share one another to follow commands The user, whether it be gestures or voice [25]. Moreover, it can be utilized to calculate the distance between two hypothetical points with precision [26].

However, only a few software developers have taken advantage of HoloLens' application development capabilities. The high cost of the HoloLens HMD unit compared to other AR techniques may be one explanation for this. Despite the high cost, many applications for modern industry have been produced [27]. Table 2 presents a summary of HoloLens in the literature review.

An important advantage of our approach is that there is no need to wear sensors, making this system easy to use and useful.

Table 1. Summary of procedure and outcomes on AR system with COVID-19 in the relevant literature.

Paper	Procedure	Outcomes
[28]	Examined the effect of COVID-19-related social constraints on AR game players' physical and mental health by a mixed methods web-based survey.	During the COVID-19 lockout, there was a large rise in the use of video games, according to this report.
[29]	developed a simple mobile application that uses augmented reality to educate the urban and rural communities on the importance of basic infection prevention practices, especially hand washing instructions to prevent Covid-19 infection.	The study found that the participant enjoyed the application and was able to follow the basic steps in it but needed more time to familiarize themselves with it.
[16]	With the help of AR, the authors of this paper addressed the case of a COVID-19-positive patient who underwent an emergency incision and drainage of an acute forearm collection.	The patient's health improved after surgery, and he had an uneventful recovery.
[17]	Aimed to enhance students' scientific literacy by distance learning with AR-based multimedia during the COVID-19 pandemic. Descriptive quantitative analysis with a pre-test and post-test design was used in this study.	AR has been shown to provide learning environments in which students can develop concept comprehension in a three-dimensional real-world setting.
[15]	To enhance student learning opportunities during COVID-19, this paper combined AR and telesurgery technologies and created a series of AR-enhanced virtual ward rounds using the Microsoft HoloLens device.	Virtual reality remote surgery training sessions have been demonstrated to be successful.
[18]	In biology learning activities, augmented reality learning media has been used, and it can help with learning during the Covid-19 pandemic by using a technology acceptance model (TAM).	Learning becomes more efficient and meaningful due to this progress and growth, which also promotes technological trends.
[19]	This research aims to improve e-learning teaching materials based on directed inquiry models with augmented reality in COVID-19 distance learning.	In terms of the validation and readability tests, developing E-Learning as teaching materials was rated very highly.
[20]	It has created an augmented reality smartphone app that places a life-size model of a Drager Apollo anesthesia system in the user's environment and instructs them on configuring the machine to function as a ventilator.	This allows the user to practice setup procedures while maintaining the 3D spatial structure of the tasks without needing physical access to the computer.

Table 2. Summary of Hololens in The Literature Review.

Paper	Description
[29]	A finger-worn camera was combined with the HoloLens to provide magnification for those with limited vision.
[30]	With the help of MR technology, HoloLens has advanced 2D graphics into 3D immersive visuals in the medical field.
[31,32]	In surgical surgeries, a similar modification was made to help with visual precision.
[33]	In pathology, this paper has examined the HoloLens for clinical and non-clinical applications.
[34]	This study provides how to add much higher resolution 3D data to a HoloLens headset in a simple way by attaching another RGBD camera to it.
[35]	HoloLens has been used for medical use to visualize organs before surgery.
[36]	HoloLens has been used for teaching dental students.
[37]	The head position provided by the AR headset (Hololens) was employed to calculate the spatiotemporal gait parameters of children with cerebral palsy.
[38]	Microsoft HoloLens has been used to further anatomy learning by providing precise 3D facial imaging.
[26]	The impact of social distance on posture and embodiment in the interaction of the human factor in AR using Hololens to measure the distance in meters was studied in this paper.

3. Method

This research aims to design and application of socially friendly AR systems to restrict the spread of COVID-19. We try to forecast the future of this area of research, concentrating on the challenges of socially supportive AR schemes for maintaining social distance during COVID-19, and identify a few research avenues that we feel will lead advancement this sector.

A total of 100 in 7th-grade kids between the ages of 12 and 13 from two different public schools made up the study's sample. There they never tried using augmented reality before.

The role of the children was only to stand on points on the ground with a known distance between these points in front of the system's camera, then read the distance from the system and compare it with the known distance between the two points, and repeat it with two other children, and so on. Then the average values were calculated. The children were a mixture of males and females.

3.1. System Description

This part covers the new AR system and components of tracking.

Augmented Reality: AR is an excellent interface method for teaching children how to maintain social distance [39,40]. In our system, augmented reality works to find the distance between two children or a group of children and draw a horizontal line, the system will issue a gentle alert sound between the two children or a group of children if the safe distance between them is reduced from the predefined distance.

3.2. System Requirements

This part explains the system requirements, the system equations, and definition; in addition to that, system architecture and the implementation of our new augmented reality technology. When all the system's hardware and software specifications are met, the system runs efficiently. The following hardware and software resources were needed for building the new system.

Hardware: In this system part, we use the Kinect developed by Microsoft, an input device for the motion sensor. It is compatible with various platforms, consisting of Windows, Xbox One, and Xbox 360 [41]. Kinect detects human movements and gestures and allows users to interact with games without using a joystick or software systems. For our new setup, we used Kinect for Xbox One. Kinect resembles a webcam with a straight bar and comprises three key components: a multi-array microphone, a depth sensor, and a RGB camera. Table 3 lists its features and specifications. The sensor captures 3D motion, recognizes faces, and recognizes voices. Kinect version 1 refers to Kinect for Xbox 360 and Kinect for Windows version 1, while Kinect version 2 refers to Kinect for Xbox One and Kinect for Windows version 2.

System Software part: Unity was used to construct the AR game for the system. Unity is a multi-platform application that was initially designed for game development but is now used in various fields, including training, children's apps, art, engineering, knowledge management, marketing, physical facilities, medical, entertainment, education, military applications, simulations, and several more. Behind the scenes, Unity handles a lot of the issues of building games and other immersive experiences. As a result, people can focus on creating and developing their games. More advanced users can communicate with and adjust these aspects as required, but less advanced users don't have to worry about it. Unity games are created in two steps. The first entails using the Unity editor, while the second entails using code, specifically C#. Unity comes with Visual Studio 2015 Community or MonoDevelop, which grants you to write C# code. The tracking component of the app was built in C# and created using Visual Studio 2015. C# is an object-oriented language with rich declarative, generic, functional, and imperative instructions, making it a multi-paradigm programming language [42].

3.3. System Measurement Distance Techniques

The calculation distance method was focused on joint coordinate positions (X, Y, Z), which is dependent on the idea of every joint being defined as a three-dimensional point. Self-written software was used, which relied on 3D space equations. In this section of the study, we describe how we built a way to inspire children to adhere to social distance by measuring the distance between a child using this system and anyone approaching it.

Our system consists of three stages in maintaining social distancing that invests in the fact that Microsoft Kinect can represent children's joints in coordinates. We process these coordinates using well-known mathematical equations that explain later and were programmed into the system. Next, if the calculated distances are less than a certain measurement (specified previously), then AR creates a virtual object simple line with a gentle sound to alert the child or teacher to maintain social distancing.

Most studies found that the safe social distance is 1.6–3.0 m after considering the aerosol transmission of exhaled big droplets during the conversation [43–45]. Figure 2 shows how well Microsoft Kinect can represent human joints by 3D coordinates.

Our method uses AR to create a child-friendly tracking world. A camera is used in our methodology, and users' path is analyzed using joint coordinate positions (X, Y, Z). Furthermore, the new method does not utilize wearable hardware sensors or indicators since the system is broadly applicable and convenient due to the unavailability of such a device. Our goal is to enable kids to interact freely with the AR system's computer graphics. Additionally, the new system is low-cost and portable, and no sensors must be affixed to the body.

Table 3. Kinect V2 basic characteristics [41].

Characteristic	Value (Range)
Color camera	1920×1080 @30fps
Depth camera	512×424
Depth distance	500 mm$\sim$8000 mm
Horizontal field of view	70 degrees
Vertical field of view	60 degrees
Full skeletons tracked	6
Skeleton joints defined	25 joints per player

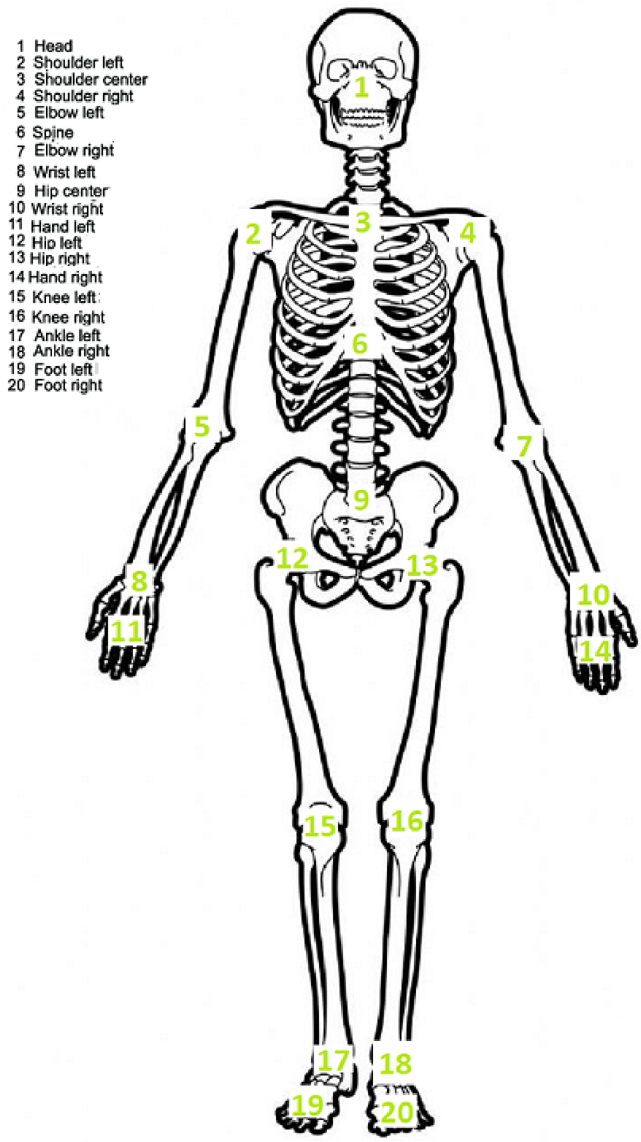

Figure 2. The names are assigned to human joints using the Microsoft Kinect.

3.4. System Equations

In our innovative approach, 3D motion patterns are captured using Kinect; using the concept of expressing each joint as a three-dimensional point, the positions of human joints are depicted in Figure 3 P_1, P_2, and P_3:

$P_1 = (X_1, Y_1, Z_1)$
$P_2 = (X_2, Y_2, Z_2)$
$P_3 = (X_3, Y_3, Z_3)$

For a given joint, the gab (D) between an old position P_1 and a new position P_2 is defined in the following manner:

$$D = \sqrt{(X_2 - X_1)^2 - (Y_2 - Y_1)^2 - (Z_2 - Z_1)^2}$$

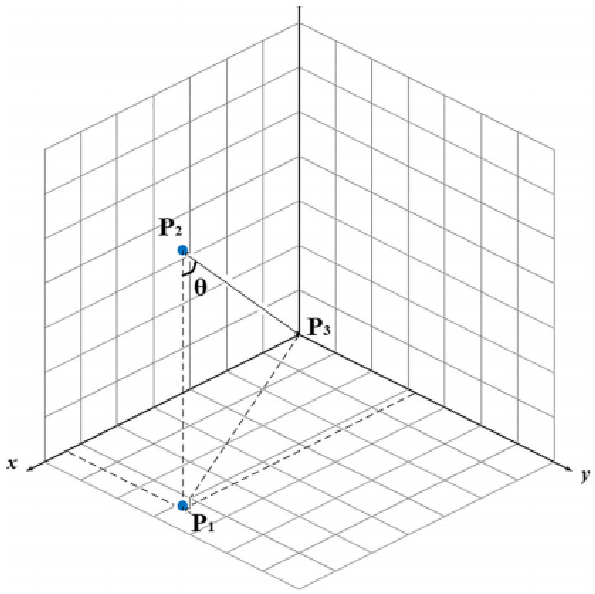

Figure 3. Three coordinates.

3.5. System Implementation

A marker-less AR technique was applied in the new method, indicating no extraneous ambient markers [46]. The AR component was built on the Unity platform. The new method used a Kinect to measure the distance between the user and the people close to him based on joint coordinates (X, Y, Z). 3D movement patterns were captured with Kinect, with each joint depicted as a three-dimensional point. Visual Studio 2015 was used to create the tracking application, which was written in C#.

3.6. Procedure

The steps for conducting the experiment are as follows:

- Seven different distances have been identified on the floor (20 cm, 50 cm, 80 cm, 120 cm, 150 cm, 180 cm, and 250 cm).
- We asked two children to stand on these identified points (the distance between them is known).
- We compared the distance determined by the system with the known distance.
- We repeated the experiment with other children and calculated the average, and the results are shown in Table 4.

Table 4. The results showed the accuracy of the system compared to the manual measurement.

The Distance Manual Measurement (cm)	The Distance Application Measurement (cm)	Accuracy %
20	18.80	0.940
50	49.10	0.982
80	78.80	0.985
120	118.53	0.988
150	149.61	0997
180	179.22	0.995
250	246.90	0.988

3.7. The Calculation Distance Method Validation

Kinect's accuracy has been verified and validated in numerous articles [47,48]. They discovered that the accuracy of Kinect V2 landmark movements ranged from moderate to excellent depending on the movement dimension, landmark position, and task completed. Consequently, the Kinect V2 has the potential to be used as a reliable and accurate clinical assessment tool. Because the measurements are valid, we used them to calculate joint distance in our system by employing ordinary equations and considering past research findings on the utilization of Kinect V2. As a result, we compared our measures to the conventional image-based and real-measurement-based approach (e.g., [49]) and discovered that the absolute accuracy was outstanding.

4. Result

When we compared the results of the application with manual measurement, the results were very accurate, and the accuracy increased when placing the cameras at the required dimensions, as shown in Table 4.

We note the accuracy of this system compared to manual measurement, and in case there is any slight difference, because the system measures the distance from the child's joint (Neck) to the other child's joint (Neck), while we measure the distance from the child and the other child from his skin to the skin of the other child.

We note here in Figure 4 that the accuracy reached the maximum value at a distance of 180 cm, and the accuracy, in general, is high accuracy, both at small and big distances, and this system can be relied on in calculating the distances between people.

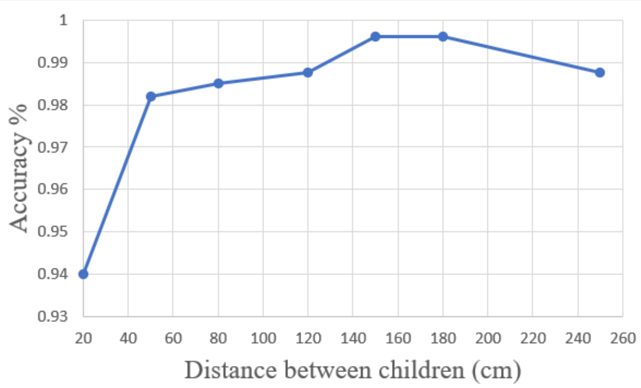

Figure 4. The relationship between the distance between children and the accuracy of the system.

Discussion

While Sutherland created the first AR interface in the 1960s [13,50], AR is still in its early stages of growth, so the potential for future applications is limitless [51,52]. However, the progress done thus far in AR research is encouraging, and it has potential in various educational settings [53].

During our COVID-19 investigation into state-of-the-art AR systems for maintaining social distance, we discovered several trends that we believe will allow AR to find better and respond to user behavior. As identified in our analysis of the literature, for an AR system to be effective and produce a decent result, it must instill personal behavior in a large number of users. Therefore, it is clear that AR is widely available and can be accessed by individuals. As AR for COVID-19 is ready to be used in homes or various long-term educational and healthcare environments, commercially available AR platforms can assess, enhance, and implement these advanced AR systems much more accessible. Furthermore, as the quantity of smartphones grows, so do their features and capabilities [54–56]. This pattern is expected to continue consumption while also making AR technology easier to develop and access.

In our literature review, we also noted that most AR studies for COVID-19 had a tiny number of participants and a short research term. In the future, we expect research to be performed on more total numbers of users and over more extended periods. In addition, the social distancing policy under COVID-19 aims to develop skills in communication, behaviors, and social interaction [5].

The employment of augmented reality systems increases the accuracy and speed of monitoring, as a tracking system and a warning system have been designed when the safe distance between children is exceeded in closed areas and classrooms. In addition to the success in achieving this system to measure the distance between individuals, especially children in schools, to protect children from diseases and respiratory diseases in particular, the new system can be used in many medicals and security fields, such as airports because it monitors several people at the same time (six people).

It is also characterized by its low cost, ease of use, and speed of response, and now work is underway to visit and integrate several cameras to monitor more people.

5. Conclusions

Social distancing is one of the most important ways to prevent the spreading of diseases, especially that related to the respiratory system. In the traditional system, the naked eye and interfere observation was used with the estimation of distance on the observer only; This causes a miscalculation in some cases. In contrast, in this study, social distancing is automatically calculated quickly and accurately. Moreover, the system does not need to wear any sensor, which makes it usable, friendly, easy, and relatively inexpensive.

In this study, a computer application was designed to monitor social distancing in closed areas, especially in schools and kindergartens. It an easy-to-use, real-time, effective, and unobtrusive technique for children. In addition to that, the system used augmented reality to help to determine the location of the violation of social distancing. The results of this study were accurate, as the achieved accuracy is about 98.5% accurate measurement compared with the unreliable distance estimation in traditional measurement method, which constitutes this system. A promising way to protect users by alarming to keep a safe distance to stop of spreading respiratory diseases in the future

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Data Availability Statement: Authors agree to make their data available upon reasonable request. It's up to the author to determine whether a request is reasonable. Data availability statements are mandatory.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chatterjee, P.; Nagi, N.; Agarwal, A.; Das, B.; Banerjee, S.; Sarkar, S.; Gupta, N.; Gangakhedkar, R.R. The 2019 novel coronavirus disease (COVID-19) pandemic: A review of the current evidence. *Indian J. Med Res.* **2020**, *151*, 147. [CrossRef]
2. Keshky, E.; El Sayed, M.; Basyouni, S.S.; Al Sabban, A.M. Getting Through COVID-19: The Pandemic's Impact on the Psychology of Sustainability, Quality of Life, and the Global Economy-A Systematic Review. *Front. Psychol.* **2020**, *11*, 3188. [CrossRef]
3. Wouters, O.J.; Shadlen, K.C.; Salcher-Konrad, M.; Pollard, A.J.; Larson, H.J.; Teerawattananon, Y. Challenges in ensuring global access to COVID-19 vaccines: Production, affordability, allocation, and deployment. *Lancet* **2021**, *397*, 1023–1034. [CrossRef]
4. Kraus, S.; Clauss, T.; Breier, M.; Gast, J.; Zardini, A.; Tiberius, V. The economics of COVID-19: Initial empirical evidence on how family firms in five European countries cope with the corona crisis. *Int. J. Entrep. Behav. Res.* **2020**, *26*, 1067–1092. [CrossRef]
5. Parimaladevi, M.; Sathya, T.; Gowrishankar, V.; Raja, G.B.; Nithya, S. An Efficient Control Strategy for Prevention and Identification of COVID-19 Pandemic Disease. In Health Informatics and Technological Solutions for Coronavirus (COVID-19); CRC Press: Boca Raton, FL, USA, 2021; pp. 83–96.

6. Qian, M.; Jiang, J. COVID-19 and social distancing. *J. Public Health* **2022**, *30*, 259–261. [CrossRef]
7. Tareq, A.; Majed, A. Social distance monitoring approach using wearable smart tags. *Electronics* **2021**, *10*, 2435.
8. Soltani, P.; Morice, A.H. Augmented reality tools for sports education and training. *Comput. Educ.* **2020**, *155*, 103923. [CrossRef]
9. Azuma, R.T. A survey of augmented reality. *Presence Teleoper. Virtual Environ.* **1997**, *6*, 355–385. [CrossRef]
10. Milgram, P.; Takemura, H.; Utsumi, A.; Kishino, F. Augmented reality: A class of displays on the reality-virtuality continuum. *Telemanipulator Telepresence Technol.* **1995**, *2351*, 282–292.
11. Wedyan, M.; Al-Jumaily, A.; Dorgham, O. The use of augmented reality in the diagnosis and treatment of autistic children: A review and a new system. *Multimed. Tools Appl.* **2020**, *79*, 18245–18291. [CrossRef]
12. Wedyan, M.; Falah, J.; Alturki, R.; Giannopulu, I.; Alfalah, S.F.; Elshaweesh, O.; Al-Jumaily, A. Augmented Reality for Autistic Children to Enhance Their Understanding of Facial Expressions. *Multimodal Technol. Interact.* **2021**, *5*, 48. [CrossRef]
13. Billinghurst, M. Augmented Reality. *Geogr. Internet* **2021**, *16* , 252–276
14. Iatsyshyn, A.V.; Kovach, V.O.; Romanenko, Y.O.; Deinega, I.I.; Iatsyshyn, A.V.; Popov, O.O.; Kutsan, Y.G.; Artemchuk, V.O.; Burov, O.Y.; Lytvynova, S.H. Application of augmented reality technologies for preparation of specialists of new technological era. In Proceedings of the CEUR Workshop Proceedings, Tarbes, France, 17–19 November 2020; pp. 181–200.
15. Luck, J.; Gosling, N.; Saour, S. Undergraduate surgical education during COVID-19: Could augmented reality provide a solution? *Br. J. Surg.* **2021**, *108*, 129–130. [CrossRef]
16. AlMazeedi, S.; AlHasan, A.; AlSherif, O.; Hachach-Haram, N.; Al-Youha, S.; Al-Sabah, S. Employing augmented reality telesurgery for COVID-19 positive surgical patients. *Br. J. Surg.* **2020**, *107*, 386–387. [CrossRef]
17. Ahied, M.; Muharrami, L.; Fikriyah, A.; Rosidi, I. Improving Students' Scientific Literacy through Distance Learning with Augmented Reality-Based Multimedia Amid the COVID-19 Pandemic. *J. Pendidik. IPA Indones.* **2020**, *9*, 499–511. [CrossRef]
18. Labib, U.A.; Subiantoro, A.W.; Hapsari, W.P. Augmented Reality Based Media for Learning Biology During the COVID-19 Pandemic: Student Admission. In Proceedings of the 6th International Seminar on Science Education (ISSE 2020), Yogyakarta, Indonesia, 28–29 November 2020; Atlantis Press: Paris, France, 2021; pp. 899–905.
19. Munzil.; Rochmawati, S. Development of e-learning teaching materials based on guided inquiry models equipped with augmented reality on hydrocarbon topics as teaching materials for COVID-19 pandemic. *AIP Conf. Proc.* **2021**, *2330*, 20025.
20. He, F.; Li, M.; Maniker, R.B.; Kessler, D.O.; Feiner, S.K. Augmented reality guidance for configuring an anesthesia machine to serve as a ventilator for COVID-19 patients. In Proceedings of the 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Lisbon, Portugal, 27 March–3 April 2021; pp. 701–702.
21. You, S.; Neumann, U.; Azuma, R. Hybrid inertial and vision tracking for augmented reality registration. In Proceedings of the IEEE Virtual Reality (Cat. No. 99CB36316), Houston, TX, USA, 13–17 March 1999; pp. 260–267.
22. Park, H.; Park, J.I. Invisible marker tracking for AR. In Proceedings of the Third IEEE and ACM International Symposium on Mixed and Augmented Reality, Arlington, VA, USA, 5 November 2004; pp. 272–273.
23. Kato, H.; Billinghurst, M. Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99), San Francisco, CA, USA, 20–21 October 1999; pp. 85–94.
24. Bai, Z.; Blackwell, A.F.; Coulouris, G. Making Pretense Visible and Graspable: An augmented reality approach to promote pretend play. In Proceedings of the 2012 IEEE International Symposium on Mixed and Augmented Reality, Altanta, GA, USA, 5–8 November 2012; pp. 267–268.
25. Vassallo, R.; Rankin, A.; Chen, E.C.; Peters, T.M. Hologram stability evaluation for Microsoft HoloLens. *Med. Imaging 2017 Image Percept. Obs. Perform. Technol. Assess.* **2017**, *10136*, 1013614.
26. Li, C. Effects of posture and embodiment on social distance in human-agent interaction in mixed reality. In Proceedings of the 18th International Conference on Intelligent Virtual Agents, Sydney, Australia, 5–8 November 2018; pp. 191–196.
27. Hammady, R.; Ma, M.; Strathearn, C. User experience design for mixed reality: A case study of HoloLens in museum. *Int. J. Technol. Mark.* **2019**, *13*, 354–375. [CrossRef]
28. Cunha, P.; Brandão, J.; Vasconcelos, J.; Soares, F.; Carvalho, V. Augmented reality for cognitive and social skills improvement in children with ASD. In Proceedings of the 2016 13th International Conference on Remote Engineering and Virtual Instrumentation, Madrid, Spain, 24–26 February 2016; pp. 334–335.
29. Stearns, L.; Desouza, V.; Yin, J.; Findlater, L.; Froehlich, J.E. Augmented reality magnification for low vision users with the microsoft hololens and a finger-worn camera. In Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility, Baltimore, MD, USA, 29 October–1 November 2017; pp. 361–362.
30. Syed, A.; Zakaria, A.; Lozanoff, S. Dark room to augmented reality: Application of HoloLens technology for oral radiological diagnosis. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol.* **2017**, *124*, e33. [CrossRef]
31. Pratt, P. Through the HoloLens™ looking glass: Augmented reality for extremity reconstruction surgery using 3D vascular models with perforating vessels. *Eur. Radiol. Exp.* **2018**, *2*, 1–7. [CrossRef]
32. Adabi, K.; Rudy, H.; Stern, C.S.; Weichman, K.; Tepper, O.; Garfein, E.S. Optimizing measurements in plastic surgery through holograms with Microsoft Hololens. *Plast. Reconstr. Surg. Glob. Open* **2017**, *5*, 182–183. [CrossRef]
33. Hanna, M.G.; Ahmed, I.; Nine, J.; Prajapati, S.; Pantanowitz, L. Augmented reality technology using Microsoft HoloLens in anatomic pathology. *Arch. Pathol. Lab. Med.* **2018**, *142*, 638–644. [CrossRef] [PubMed]

34. Evans, G.; Miller, J.; Pena, M.I.; Macallister, A.; Winer, E. Evaluating the Microsoft HoloLens through an augmented reality assembly application. *Int. Soc. Opt. Photonics* **2017**, *10197*, 101970V.
35. Cartucho, J.; Shapira, D.; Ashrafian, H.; Giannarou, S. Multimodal mixed reality visualisation for intraoperative surgical guidance. *Int. J. Comput. Assist. Radiol. Surg.* **2020**, *15*, 819–826. [CrossRef]
36. Zafar, S.; Zachar, J.J. Evaluation of HoloHuman augmented reality application as a novel educational tool in dentistry. *Eur. J. Dent. Educ.* **2020**, *24*, 259–265. [CrossRef]
37. Guinet, A.L.; Bouyer, G.; Otmane, S.; Desailly, E. Validity of Hololens Augmented Reality Head Mounted Display for Measuring Gait Parameters in Healthy Adults and Children with Cerebral Palsy. *Sensors* **2021**, *21*, 2697. [CrossRef]
38. Kumar, N.; Pandey, S.; Rahman, E. A Novel Three-Dimensional Interactive Virtual Face to Facilitate Facial Anatomy Teaching Using Microsoft HoloLens. *Aesthetic Plast. Surg.* **2021**, *45*, 1005–1011. [CrossRef]
39. Ellis, L.A.; Lee, M.D.; Ijaz, K.; Smith, J.; Braithwaite, J.; Yin, K. COVID-19 as 'Game Changer'for the Physical Activity and Mental Well-Being of Augmented Reality Game Players During the Pandemic: Mixed Methods Survey Study. *J. Med. Internet Res.* **2020**, *22*, 25117. [CrossRef]
40. Hanafi, H.F.; Wahab, M.H.; Wong, K.T.; Selamat, A.Z.; Adnan, M.H.M.; Naning, F.H. Mobile Augmented Reality Hand Wash (MARHw): Mobile application to guide community to ameliorate handwashing effectiveness to oppose COVID-19 disease. *Int. J. Integr. Eng.* **2020**, *12*, 217–223. [CrossRef]
41. Microsoft. *Kinect for Windows*; Microsoft: Redmond, WA, USA, 2022.
42. Jackson, S. *The Art of Neural Networks Using C Sharp*; CreateSpace Independent Publishing Platform: North Charleston, SC, USA, 2016; pp. 1–128.
43. Sun, C.; Zhai, Z. The efficacy of social distance and ventilation effectiveness in preventing COVID-19 transmission. *Sustain. Cities Soc.* **2020**, *62*, 102390. [CrossRef]
44. Varela, D.G.; Fedynich, L. Leading schools from a social distance: Surveying south texas school district leadership during the COVID-19 pandemic. *Natl. Forum Educ. Adm. Superv. J.* **2020**, *38*, 1–10.
45. Ahmed, I.; Ahmad, M.; Rodrigues, J.J.; Jeon, G.; Din, S. A deep learning-based social distance monitoring framework for COVID-19. *Sustain. Cities Soc.* **2021**, *65*, 102571. [CrossRef]
46. Monte, J.P.S.D.; Lima, F.P.M.; Simoes, L.S.; Figueiredo, J.; Kelner, J. Model based markerless 3D tracking applied to augmented reality. *SBC J. Interact. Syst.* **2010**, *1*, 2–15.
47. Galna, B.; Barry, G.; Jackson, D.; Mhiripiri, D.; Olivier, P.; Rochester, L. Accuracy of the Microsoft Kinect sensor for measuring movement in people with Parkinson's disease. *Gait Posture* **2014**, *39*, 1062–1068. [CrossRef]
48. Otte, K. Accuracy and reliability of the kinect version 2 for clinical measurement of motor function. *PLoS ONE* **2016**, *11*, e166532. [CrossRef]
49. Li, K.H.; Lou, S.J.; Tsai, H.Y.; Shih, R.C. The Effects of Applying Game-Based Learning to Webcam Motion Sensor Games for Autistic Students' Sensory Integration Training. *Turk. Online J. Educ. Technol.-TOJET* **2012**, *11*, 451–459.
50. Zhou, F.; Duh, H.B.-L.; Billinghurst, M. Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. In Proceedings of the IEEE/ACM International Symposium on Mixed and Augmented Reality, Cambridge, UK, 15–18 September 2008; pp. 193–202.
51. Alkhamisi, A.O.; Arabia, S.; Monowar, M.M. Rise of augmented reality: Current and future application areas. *Int. J. Internet Distrib. Syst.* **2013**, *1*, 25. [CrossRef]
52. Carmigniani, J.; Furht, B.; Anisetti, M.; Ceravolo, P.; Damiani, E.; Ivkovic, M. Augmented reality technologies, systems and applications. *Multimed. Tools Appl.* **2011**, *51*, 341–377. [CrossRef]
53. Lin, C.Y. Augmented reality in educational activities for children with disabilities. *Displays* **2016**, *42*, 51–54. [CrossRef]
54. Ghose, T.; Namboodiri, V.; Pendse, R. Thin is green: Leveraging the thin-client paradigm for sustainable mobile computing. *Comput. Electr. Eng.* **2015**, *45*, 155–168. [CrossRef]
55. Hung, S.H.; Hsiao, S.W.; Teng, Y.C.; Chien, R. Real-time and intelligent private data protection for the Android platform. *Pervasive Mob. Comput.* **2015**, *24*, 231–242. [CrossRef]
56. Mitchell, E.; Monaghan, D.; O'Connor, N.E. Classification of sporting activities using smartphone accelerometers. *Sensors* **2013**, *13*, 5317–5337. [CrossRef] [PubMed]