Vision based 3D Gesture Tracking using Augmented Reality and Virtual Reality for Improved Learning Applications

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***Abstract*—3D gesture recognition and tracking based augmented reality and virtual reality have become a big interest of research because of advanced technology in smartphones. By interacting with 3D objects in augmented reality and virtual reality, users get better understanding of the subject matter where there have been requirements of customized hardware support and overall experimental performance needs to be satisfactory. This research investigates currently various vision based 3D gestural architectures for augmented reality and virtual reality. The core goal of this research is to present analysis on methods, frameworks followed by experimental performance on recognition and tracking of hand gestures and interaction with virtual objects in smartphones. This research categorized experimental evaluation for existing methods in three categories, i.e. hardware requirement, documentation before actual experiment and datasets. These categories are expected to ensure robust validation for practical usage of 3D gesture tracking based on augmented reality and virtual reality. Hardware set up includes types of gloves, fingerprint and types of sensors. Documentation includes classroom setup manuals, questionaries, recordings for improvement and stress test application. Last part of experimental section includes usage of various datasets by existing research. The overall comprehensive illustration of various methods, frameworks and experimental aspects can significantly contribute to 3D gesture recognition and tracking based augmented reality and virtual reality.**

Keywords—Augmented reality; virtual reality; 3D gesture tracking

I. Introduction

Dexterity is one of the most important driving forces of human intelligence. Our hands have enabled us to create arts and crafts as well as build massive constructions alike. In this age of technology, human use their hands to interact with electronic devices everyday. Touch and gesture input have become part of common life. Nowadays, people interact with digital devices by using touch screen displays or trackpads. Two dimensional (2D) touch screens are basically offered by the latest technology. However, mobile phone touch screens constrain us within a small space of the device. In this context, virtual reality refers convincing visual rendering of the simulated objects in lieu with manipulating them in a fast, precise, and natural way [1], augmented reality indicates machine generated image on user's view of the real world to enable composite view [56] and hand gesture refers movement of the hand to enable meaningful interpretation [60]. To extend the interaction space from 2D surface to real 3-dimensional (3D) space, this research investigates currently existing vision based 3D gestural architectures for augmented reality and virtual reality. The core goal of this research is to present comprehensive investigation on tracking and predicting hand gestures from RGB camera images and interact with virtual objects in mobile phones. Huge investments of the big technology companies on augmented reality and virtual reality has broadened the applications of this case where a relatively new branch has been introduced towards the direction of gesture tracking and recognition in the domain of computer vision and pattern recognition.

Tracking the hands of an user makes it a difficult task when the tracking camera is also moving, which is the case for augmented reality and virtual reality. While there have been numerous previous research works for tracking hands, the problem still remains as a research interest. Because of the progress in the area of computer vision and machine learning, computers are now capable of tracking hand gestures and pose through various techniques. This research analyzed those previous works to track hand gestures and interact with objects with hands in augmented reality and virtual reality. In the early days of this field, there were numerous approaches made with traditional image processing techniques to detect and track hands. But in the recent days, most of the research has been performed with respect to machine learning approaches. This research presents the benefits and shortcomings of these approaches in lieu with presenting existing experimental analysis with different approaches.

II. Core Background Study

Augmented reality and virtual reality have been a research interest for a long time. Researchers have been trying to do camera tracking based augmented reality and virtual reality for a long time. Recently these two domains have become a big interest of research because of advanced technology in mobile phones and smartphones. In recent years, there have been a lot of progress in the processing capability of smart phones. Because of this, handheld mobile phones can compute the necessary amount of data to perform camera tracking as well as rendering on corresponding display. In recent years, there has been a lot of progress in recognition and tracking of the human face and we have seen a rise in user interest in such kinds of applications.

This research also relies on the research that has been done to track plane surfaces as well as wall or vertical objects and render digital objects on them to deliver the experience of augmented reality and virtual reality. There has been enormous research on this area and there have been massive breakthroughs in the area [56][60]. There have been games based on augmented reality and virtual reality where a planar surface such as floor or road is tracked and on the tracked surface a game object is drawn and players use their camera feed to see the object augmented on the video feed of that planar surface. There have also been a lot of applications to visualize shopping products in augmented reality and virtual reality. Big technology companies like Google and Apple have their own libraries to implement augmented reality and virtual reality. Furniture vendors such as IKEA has launched their app in which users are able to place a virtual 3d object in their living room and judge which product will look good in their room as well as the environment. These usages and demands of such applications have turned lots of active research interest in the area of augmented reality and virtual reality.

In the past, there has been research on recognizing human hands and tracking them. In the early days of the research, recognizing the hand and tracking the hand in an image was done by offline image processing as this was a computationally heavy task. After some successful research, it has also been possible to track human hands in real time using a web camera and a desktop pc as technology progressed. Now with the advancement in neural networks, feature tracking and modeling the network has been done by neural networks, and because of the easiness of modeling a human hand as an object for tracking has been easier. Now, there has been active ongoing research for tracking human hands via mobile phone camera as well as recognizing the pose of the hands in a camera frame. Research interest of this proposed investigation relies within the research of tracking and recognizing human hand pose and tracking it in continuous frames.

III. Qualitative Analysis on Methods

Early researchers used augmented reality and interaction with personal interaction panels which includes creating menu system and 3D interface [17] [39]. The Positive side of these researches were that there was instant feedback from users. However, in accuracy and unreliability were the main area of concern in these researches. Collaborative geometry learning based object constructions shown in Fig. 1 is an active area for the researchers which includes augmented reality by hybrid hardware and software setup [18][47]. However, requirement of comprehensive evaluation of the practical value such as development of substantial educational content demands for further investigation for real use in the classroom for teachers or students. Hand gesture recognition and AR marker recognition were designed previously for geometry learning [19][46]. However, applications for learning 3D geometry by these researches could also be expanded for multi-device environments. Observation on classes and assignments for the students by letting them work with augmented reality is an interesting broad domain which mostly depends on educational design research [20] [43] [44] [46] [48]. However, existing curriculums in the schools at junior level, more passiveness, less constructive contents in the context of teaching media used by researchers, limited understanding of the roles by teachers, lack of ability to create interesting teaching contents demand of extensive investigation in this area of research. Marker based positional tracking as well as picture based positional tracking is another common method among previous researchers due to easiness of implementation for these systems [21][22]. However, due to the limited validation inside classroom environments instead of real world scenarios, these researches could not provide expected satisfactory results. Some augmented reality researchers took gamification a step further in the gaming industry [23]. However, gamification hugely depends on users and participants feedback due to new technology.

For virtual reality based education systems are more reliable to design and construct geometries [24]. Unity3D engine and Vuforia plugin made the tasks easier using camera tracking [25] although previously tested to a small group of students demands further investigation. QR code based tracking method was an old method in this context still attracts researchers since these are quick and easy to implement [26]. However, with the aspects of language, contents, and design QR based tracking requires further validation. Surface tracking, geometry modification and structure from motion pipeline (SFM) has been considered as another potential subsets of augmented reality and virtual reality [27] [28] [29] [30]. Among these methods, structure from motion has been holding higher research interest among researchers. However, due to recent advanced computing systems and user friendly process to construct and visualize point clouds make these research challenging for practical usage although there have been significant improvements in visual quality which still needs deep focus in terms with reducing computational complexity [28]. Perspective geometry [29] is another option by the researchers which has been suffering significantly from complexity and dependency on external hardware. In addition, there are significant errors observed in these kinds of systems and video rendering through augmentation takes a lot of computational cost [29]. Planar surface tracking with the inclusion of background and foreground subtraction is one of the successful method in the area of surface tracking [30]. However, planar surface tracking method did not attain good frame rate although later occlusion management has been improved significantly by the recent advancement in machine learning technology. In the design industry, AR and VR has the most usage observed in the previous research. Some degree of success were found for spatial skill learning where specialized applications were designed and developed in order to put them into training purposes [31]. Existing technology as in research by [32] and [41] were used to build 3D models for visualizing augmented reality which was developed for improving students understanding capability. However, users for these applications requires some degree of geometry and 3D modeling skills. User experience on the existing applications is also another area for improvement observed by the researchers during implementation of gesture control [33].

In this context, hand pose estimation and shape recognition from single hand image or video stream were focused most by the researchers of such gestures and has many applications in augmented reality and virtual reality. Convolutional neural network and 3D hand meshing using LBS were used to recognize hand shape and pose estimation from depth images [34] and initially from RGB images. As part of hybrid approach, hand pose estimation was done from RGB images by adopting multiview RGB images and depth data [49]. However, reliable size of the dataset in lieu multidimensionality, hand to objects and hand to hand interactions were not considered in these researches in order to make the hand shape and pose estimation more robust. Deep learning [40] and monocular RGB cameras advances estimation of hand shape from RGB images [34]. In terms with datasets, researchers put effort to make hand gesture datasets for acceptable validation, however, models trained on one dataset did not perform well on other datasets due to lack of generalization in the training data [35] because researchers found significantly improved results in indoor and outdoor by exploring validation in generalized datasets. In this context, vision based Deep Convolutional Neural Networks (CNNs) attributes the success for hand pose estimation [36] [54] using depth cameras, depth map data with the analysis of effectiveness based on detection based method versus regression based methods. From different viewpoint perspectives, neural network was deployed to model human hands and pose in virtual reality, i.e. MEgATrack: Monochrome Egocentric Articulated Hand-Tracking [38]. In MEgATrack, depth based approaches was used and generated training data from model based tracking system. Research by [38] used DetNet to track hands KeyNet to predict 21 key-points in hand from the cropped image based on the bounding box provided by DetNet in the previous step. However, hand scale and distance recognition were their main challenge to achieve accuracy. MediaPipe pipeline shows prominent progress for handheld mobile phone based hand tracking and hand gestures recognition [37]. Research by [37] used single RGB camera consists of palm detector to provide bounding box of the hand and hand landmark model to predict hand skeleton. However, for multidimensional data, performance of MediaPipe is still not resolved.

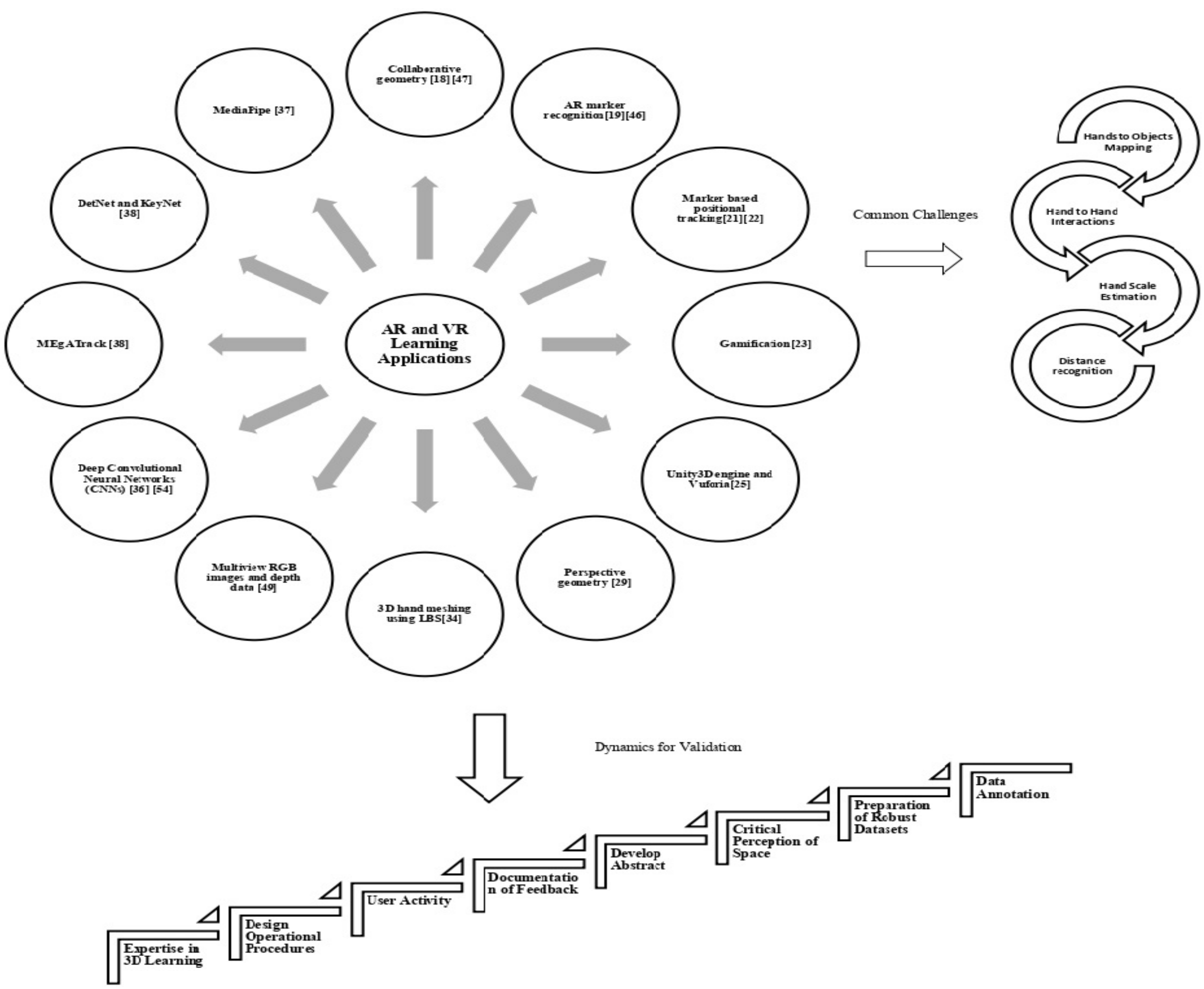

Fig. 1. Methods and Challenges for Augmented and Virtual Reality based Learning Applications.

IV. Step Wise Frameworks Analysis

Majority of the research done in the earlier days of augmented reality and virtual reality consisted of using specialized hardware. Frameworks using Construct3D involves creating user interface and then tracking user hand movement and giving input using pen-like tools [17]. Other similar methods also consist of similar frameworks. Researcher's implemented 3D layer based interaction systems [18]. These methods also require extensive hardware setups and screen projection. For Marker based augmented reality tracking, initial step is to acquire the markers and recognize them and track them in the scene. When combined with software design methodologies, applications become easier to develop and get feedback from users and participants. In these cases, first step is to choose the target participants, users or students, then making prototypes and improving it further [20] [21] [23] [25] [45]. Testing into small groups first and then to a broader range of participants also brings out better results for research [26].

Tracking surfaces for augmented reality was adopted for similar approaches by the second group of researchers. For 3D reconstruction, steps are to acquire a large number of images of the target object and then reconstruct it using different structures-from-motion pipelines [27] followed by rending these objects in 3D and shown on top of video camera feed [28]. In this context, most of the pipelines use offline processing step followed by real time camera tracking and rendering. In the same focus, foreground and background separation techniques provide better results for occlusion management [30]. Applying virtual reality and augmented reality for practical purposes have seen significant increase in recent times. By interacting with 3D objects in virtual reality, users get a better understanding of the subject matter. The primary requirement for these projects is expertise in 3D geometry modeling and then designing operational procedures for users or participants and observing user activity and documentation of feedback [32] [33] [47]. Investigating students understanding of the topic before going into development of the project is suggested by researchers, since that allows researchers to get to know their participants perspective better. Then allowing students to learn and practice by themselves is another good way to get feedback [31]. Researchers have also tried developing abstract and critical perception of space before putting students to use the applications [32].

Preparation of robust datasets and annotation for hand tracking were core research focus for one subset of researchers which not an easy tasks where most researchers prefer training models on synthesized hand gesture data. Straightforward solutions like human pose tracking and applying them to track hand and estimate pose were preferred by some researchers [34] where usage of multiview geometry was a popular approach to attain hand images [35] [41] required heavy hardware set up and accurate annotation manually [50]. Single shot detection is a preferred for image based tracking [58] whereas multicamera tracking in virtual reality is another favorable approach where computational complexity was a big concern.

V. Experimental Analysis

Several works were done in the past for 3D gesture tracking and recognition. A robust gesture detection system by using a single camera is a challenging issue in the area of computer vision [58]. The camera quality is also a challenging part in this context. Most of the researchers that are based on augmented reality uses marked gloves shown for accurate and reliable fingertip tracking [1] [2]. Few methods depend on the object segmentation for the shape or temperature [3] [4] [5]. In most devices, thermal based approaches and expensive infrared cameras are needed but not given in the previous research work. Most of the gesture tracking devices like Kinect are based on depth sensors. These gesture tracking devices are only available for stationary systems because of size and power limitations [6]. In few of the systems, color-based techniques were used but color-based techniques are sensitive for the lights and degrade the quality of gesture recognition and tracking process. Template matching and contour-based techniques suits well for these types of specific hand gesture recognition and tracking [7]. Few systems were designed based on the syntactic analysis of hand gestures by using syntactic pattern recognition paradigm [8]. Few approaches that were designed for smartphones and tablets use accelerometer-based methods with the device's acceleration sensor [9] [10]. For detecting the fingertips, in some gesture based interaction, visual color markers are used [11]. Several researches were proposed for recognition and tracking system of hand gesture which was based on low level edge orientation features and can be implemented by using the hierarchical scoring of the similarity between the query and database images. In these researches, fingertips and all the hand joints that consist of the finger joints are marked from the database. Then, overall system saves the exact position of the marked points with the help of the image coordinates and finds out the relation between the joints in the form [12]. Some researches were conducted to track 3D photos of the human body by using sensor-fusion algorithms [13] [14]. A sensor-fusion method that can track the articulation of the hand in the presence of excessive motion blur was proposed using HPF framework [15]. Gyroscopes are very popularly used when it comes to human body pose estimation but the investigation for the use of gyroscope for hand pose estimation is not completed yet. IMU sensor was used to assist model-based tracking to get more robust performance [16].

Research that was performed in the education domain requires multiple accounts of user questionnaire and feedback. Researchers let their participants use the application and later ask questions to acquire feedback from participants [17] [18] [19]. Researchers made attempts by giving primary knowledge about the subject before exposing them to the real application and later tested again their knowledge level to measure the improvement after using their applications [20] [43]. Extensive data documentation was required for these experiments. In classroom setups, researchers observed students using their application and later asking questions to get feedback. Making a prototype before the final application testing was used by some researchers [23] [45]. In every case, user questionnaires and recording student improvement in learning is the mandatory step for these researches.

Researches also included expert assessment to validate their research [26].

Surface tracking was experimented by researchers for a long time. Researchers experimented with different methods and choose suitable approaches for their research where it is common to experiment with multiple methods [27] [29]. In addition, it is also emphasized to stress test the application under different kinds of motions [39]. A subset of researchers utilizes a preprocessing stage for achieving better performance [30].

In recent years, augmented and virtual reality have been a subject of major experimentation to explore possibilities of different use cases. Researchers investigated students understanding before and after using the applications. Also, letting the participants find how to use the application is one more approach that returns good results [31]. One more investigation was done that lets users acquire little knowledge about a topic beforehand and then let them, use the application and quiz on how much they have improved [32]. Putting augmented reality as well as virtual reality into practical training purposes have brought out better results among technicians. Researchers verified their research by evaluating the participants knowledge and skill after each subsequent phase [33].

Usage of multiple datasets is common for researchers using different parameters and including or excluding different levels of details while annotating the data [34,51-53,59-63]. or FreiHAND, researchers performed cross-dataset generalization to achieve improved results [35]. Evaluating different levels of details and annotation was performed to optimize research effort. Numerous datasets are currently available for hand gesture recognition training [36, 55-57, 64-68] mentioned in Fig. 2. Availability of datasets is a major reason for the increase of research interest for augmented reality and virtual reality domain. For Google MediaPipe, researchers created their own annotated dataset of hand images in the wild, in-house hand images and synthetic hand gesture dataset [37]. By utilizing different datasets for their specific purposes, MediaPipe achieves greater efficiency in terms of performance.

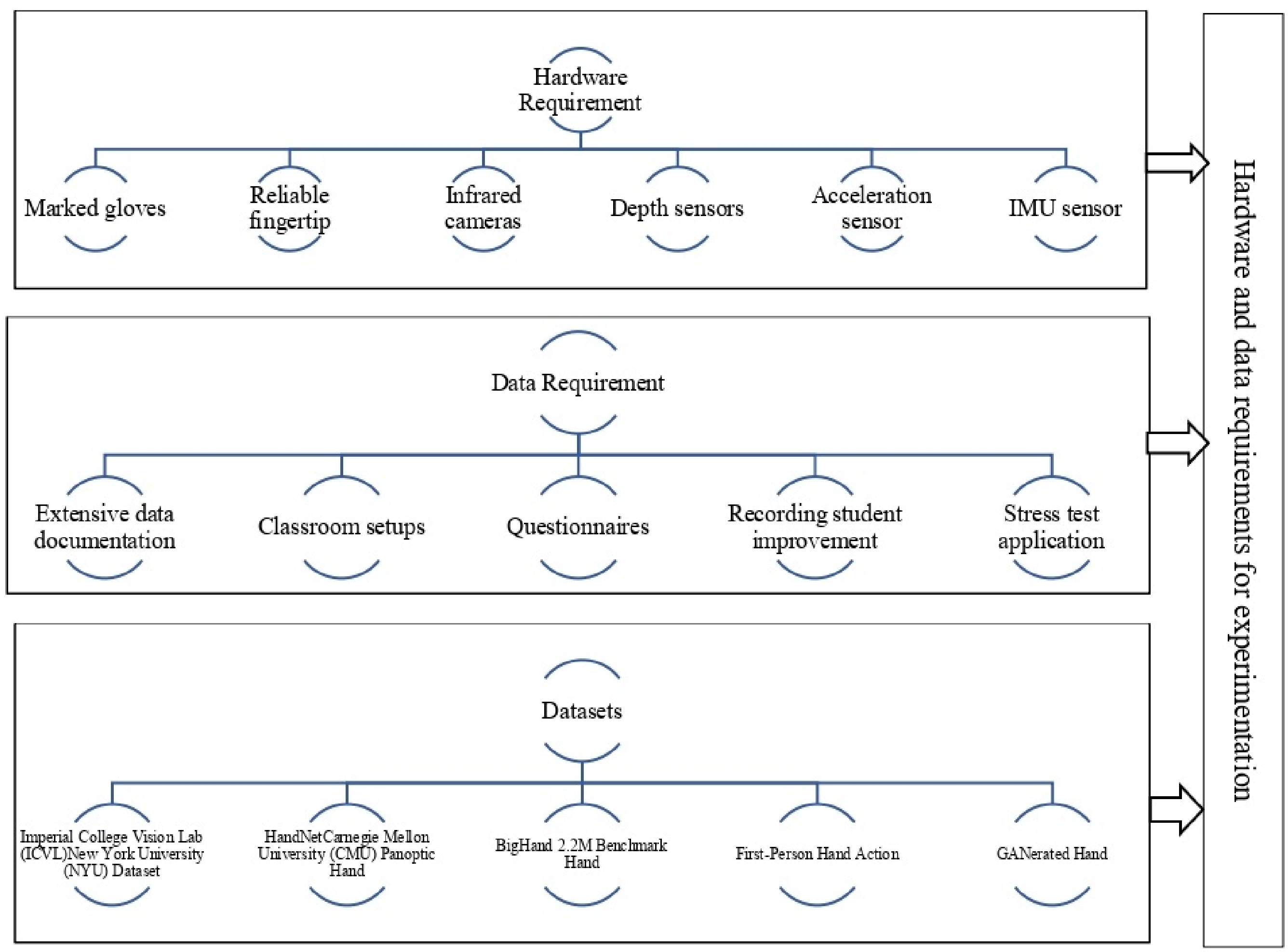

Fig. 2. Experimental Requirements.

VI. Observation and Discussion

This research observes that in recent years there has been a significant amount of research was done in computer vision in the context of 3D gesture tracking based on augmented reality and virtual reality. With the advancement of computer processing power, it is possible to compute and find solution quickly and more accurately. In the earlier days of research on augmented reality and virtual reality there have been requirements of customized hardware support and even so the performance and quality was not satisfactory. At a later stage there has been significant research on tracking planar surfaces as well as tracking objects. By tracking a surface camera position, efficient detection was proposed. On top of those technology, occlusion handling was performed. With greater computer processing power tracking have been more stable in recent times. While there were requirements for heavy hardwares and sensors, after a decade, now it can be performed on a handheld mobile device.

By introducing augmented reality and virtual reality into media, their popularity and research interest have been increased. Comprehensive investigation by this research has observed significant amounts of research as well as practical usage of augmented reality and virtual reality. In the early stage of research for these domains, there was requirement for specialized input pens as well as specialized input panels for interacting with the system. Naturally humans are used to use hands for performing day to day tasks, for this reason tracking hands has been a great interest in recent times. While the technology is not perfect, yet there has been a significant amount of improvement and technological advancement in the past few years.

This research also observed that big technology companies like Microsoft have been working with HoloLens technology which is a high-end mixed reality platform [42]. Google and Apple have their own augmented reality platforms named ARCore and ARKit respectively and there has been a rise in augmented reality applications ever since. Facebook has shown interest in Virtual Reality and with Oculus Virtual Reality systems they have been outperforming themselves every year.

While there have been significant hardware improvements, there has not been improvement in user experience as per with time. Human computer interaction research domain has been working on improving user experience for a few decades now a days and result is improving day by day. There have been touch input display for mobile phones and gesture tracked hand controller for gaming console systems. However, it is high time to investigate more on making the interactions more meaningful for human beings by making interaction between humans and computer more natural.

VII. Conclusion

Hand gesture detection based on augmented reality and virtual reality is an active and ongoing research field which are attracting a lot of research towards the topic. The vastness of both topics makes it interesting to pursue research problems further. In this research, investigation of different usages and implementations of augmented reality and virtual reality based systems was elaborated and discussed in detail. Besides, possibility of neural network based hand palm tracking and hand gesture tracking was illustrated comprehensively. This research found that hand interaction in augmented reality and virtual reality can be achieved with acceptable accuracy based on improved user experience. In addition, this research also emphasizes to focus on usages of augmented reality and virtual reality, tracking surfaces as well as tracking and 3D reconstruction of real life objects in the context of hand palm detection, hand tracking and detecting symbolic gestures from finger shapes. With the keypoint from hand landmark points, 3D mesh can be rendered and that 3D mesh can also be used to interact with augmented and virtual objects in future.

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