

RESEARCH ARTICLE

Applications of Augmented Reality in Neurology: Architectural Model and Guidelines

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ABSTRACT Neurology is considered as one of the most challenging fields of medical science due to the complexity of the nervous system in human body. The treatment processes of the patients suffering from neurological disorders are greatly influenced by the advancements in technology. In this regard, the infusion of augmented reality (AR) has immensely improved patients' and healthcare workers' experiences in the field of neurology. Several efforts are being made by the community to introduce various applications of AR for patients as well as for healthcare workers in neurology. This study systematically examines the applications of AR in neurology and synthesizes their uses and impacts in the treatment and assistance of the patients suffering from neurological disorders as well as in the assistance of healthcare workers. The results reveal that most of the AR applications are used for motor disorders while lesser systems are designed for patients with degenerative diseases, most of them being task assistance systems. Moreover, the use of AR applications leaves both long-term and short-term impacts in improving the quality of patient's life. Furthermore, there is a need of introducing more interactive AR systems for patients with degenerative diseases as well as exploring the possibility of using such systems for mental rehabilitation. It has also been identified that there is a potential to develop AR applications for healthcare workers, to train and assist them through simulations. In addition to reviewing the AR applications, this work proposes a taxonomy of AR applications in neurology posing different dimensions including scope of AR, type of neurological disorder, and impact of AR assistance on patient's life. Furthermore, this article also highlights challenges of using AR applications in neurology. Based on the identified challenges, guidelines to design AR systems are suggested for application designers and developers to help them design and develop more useful AR systems. Lastly, this work proposes an architectural model to design the AR systems for patients suffering specifically from degenerative or movement neuro-disorders in order to guide the future research of AR usage in neuroscience.

INDEX TERMS Augmented reality, application, neurological disorder, neurology.

I. INTRODUCTION

Neurology is a term used in medical science to describe the functionality of the central nervous system (CNS) and brain [92]. Neurological disorders are caused by physical impairment of the brain, nerve, or spinal cord [93]. Other causes to have these disorders could be because of changes in certain biochemical aspects. Even though the cause may

The associate editor coordinating the review of this manuscript and approving it for publication was Michele Nappi.

be unidentified but the effects or symptoms on CNS can be perceived [38]. Neurological disorders may cause symptoms that are related to brain activity such as thinking and analytics. These disorders may also cause problems in muscle functionality and balance. Certain chronic conditions such as hormonal imbalance may also result due to these disorders. However, temporary conditions induced due to the environment or certain events may cause hurdles in brain functionality but are not classified as neurological disorders. These are psychiatric illnesses that are reversible, such as

stress, anxiety, or temporary memory loss [89]. The patients of neurological disorders could globally be in any part of the world; however, the areas where the growing population is over 65 years of age tend to have more patients suffering from these disorders [93].

Traditionally, the neurological disorders are treated with medication [90]. In some cases of symptoms where patient may have loss of movement, balance, or loss of sensation in any part of their body, physical rehab may be provided in order to maintain the functionality of patients' limbs [88]. Training activities may also be given to patients in order to maintain their thinking and analytical abilities [91]. These treatment methods can be challenging for doctors and patients as they are often time consuming, tedious, and may differ from real life scenarios. Patients could also lose interest in these activities and may find them very different from what they may experience in real life. Doctors experience difficulties in treating patients with neurological disorders as brain and CNS is a very complex system to handle with such forms of treatments. Normal medical reporting tools often rely information in form of 2D images (x-rays, CT scans, MRIs) which are not very visualize-able [94]. In addition, there is very less training simulators available for healthcare workers to train for difficult medical procedures such as brain surgeries [91].

Recently with the advancements in technology, augmented reality (AR) has made its way into medical science. AR is a technique that modifies a real-life environment by augmenting through sound, visual elements, or other sensory stimuli [5].

The AR involves different technologies for enabling the real-time environment of computer-generated content by displaying live videos. AR is based on VR, which interacts with a virtual world and simultaneously has some interdependence with the real world [95]. The augmented reality is considered meaningless in its own but it starts making sense by considering the humans and how they conceive the real work [5].

The treatment process for patients suffering from neurological disorders as well as training of doctors, nurses, surgeons, and hospital staff for dealing with patients' ailment has significantly improved with the use of AR technology [42], [70]. The instructiveness of AR technology allows the treatment process for patients to be a lot more user-friendly by providing them with experience with real-life scenarios in an augmented world. It not only provides enhanced learning experiences to doctors but also gives them special provisions in terms of 3D visualization of the human body, digitizing patient records, and augmented treatment practices such as surgery simulations [8], [16].

The conventional approaches to treat neurological disorders are in place; however, AR technology is infused to enhance and support existing techniques for treating neurological disorders. The traditional approaches have their significance and roles in treatment but AR is used to treat patients suffering from neurological disorders with the intent to provide better user experience of AR applications and

more natural input and output interaction methods. Despite the demonstrated effectiveness and the significance of using AR applications in neurology [16], [18], [21], rare work is observed, which synthesizes the use of AR applications in terms of the scope, the neurological disorders these applications treat, and the impact of using these applications on patients' journey.

The existing systematic literature reviews (SLRs) and surveys in the specified field of study are either holistic [95], [96], which generally investigates the applications of AR in various fields or too narrow, which examine the use of AR applications for particular neurological disorders [99] or to support particular stakeholder in order to perform specific tasks [97], [98], [100]. This triggers the need to conduct a study that comprehensively evaluates the use of AR applications in the field of neurology to perform various tasks related to different stakeholders including doctors, healthcare workers, and patients.

The main goal of this research is to examine various applications of AR in neurology and find the types of neurological disorders being treated using AR. To the best of our knowledge, no study in past posed a review of AR applications' usage in neurology. Based on the findings of this review, this study suggests guidelines for designing AR systems to enhance the user experience. Moreover, a taxonomy for the use of AR technology in the field of neurology has also been presented in this article. Furthermore, this work proposes a dedicated AR apps structure to overcome the challenges faced by patients with recognized neurological disorders. A user-friendly design model and layered architecture for neurological disorder apps based on the identified gaps has also been presented in this study.

The rest of this article has been organized into the following sections. Section II describes the AR systems that are being used in the field of neurology. Section III defines the research methodology along with data analysis exhibiting the responses to the research questions. Section IV describes the discussion and implications, which poses the taxonomy, and gaps and challenges. The sub-system division of physical therapy apps and an AR system architecture for neurological disorders are also proposed in this section. Lastly, the Section V provides the conclusion by highlighting the major findings of this work.

II. AR SYSTEMS IN NEUROLOGY

This section presents the work done in neurology using AR applications specifically related to the patient's treatment and assistance journey. AR applications may also be used for healthcare worker's training or facilitations who are treating patients with neurological disorders. The use of AR, as recommended in [83] and [84] is a technique to improve motion recovery through action observation. The majority of the AR systems proposed in the literature for rehabilitation activities require a person to wear external devices or sensors.

Rehabilitation for stroke patients involves regaining motion in the afflicted body parts, primarily the limbs,

through intense, skilled training exercises. Muscular tasks such as grasping, stretching, and holding objects of everyday usage (such as coffee making, cellphones, TV remotes, etc.) are used in various rehabilitation procedures [9]. Task-specific rehabilitation, like treadmill exercise with fractional body weight support and hip and knee extension workouts, is all part of lower limb rehabilitation [24]. The parts of the brain damaged by stroke are activated through repetitive exercise under the direction of a therapist.

Exergaming (exercise plus gaming), also referred to as serious gaming, has gained favor in the past few years as a low-cost rehabilitation strategy that makes repetitive training enjoyable and exciting [80], [82]. Serious games for rehabilitation are created with the following criteria in view: (a) They must be entertaining to play; (b) the output should be clear, and they should be accompanied by virtual reality (VR) awareness [79].

Although at-home physical training for stroke rehabilitation using AR and VR techniques is becoming increasingly widespread, most current options concentrate on a single aspect of recovery.

Hondoriet *al.* developed an AR method for teaching unilateral upper-extremity actions like dripping water [86]. However, clinical medicine believes that full benefits from stroke rehabilitation require the collaboration of all damaged brain regions, as a stroke can destroy brain cells in several areas [87].

AR Games by Leon *et al.* are simple AR systems for home rehabilitation after a stroke. Such a system uses AR technology to provide an interactive and motivational environment, based on exergames, to perform reaching tasks and provide a performance score that can be useful for the motivational purpose [37]. However, these systems are designed for home-based rehabilitation and don't involve the supervision of a therapist which is necessary in most cases. Moreover, these systems are only being used for shoulder rehabilitation.

ARIS (Augmented Reality-based Illusion System) [41], [43] is a system to develop a rehabilitation game exercise with visual and audio feedback, computer vision technology to create an illusory environment, and signal processing to monitor the performance of trained muscles via EMG signal (electromyography signal). AR System by Colomer *et al.* [74] is a portable and low-cost mixed reality tabletop system for upper limb rehabilitation. However, these systems are only designed for clinical rehabilitation and target only one specific area.

MirrARbilitation and SleeveAR [42], [44], [69], [70] are AR rehabilitation systems with gesture recognition based on marker-less body tracking technology. These systems guide and motivate the user during the execution of a reaching task, allowing the physiotherapist to set the target object angle. In addition, these systems provide score points and give instructions to avoid the incorrect execution of movements. These are specifically designed to fit in a home environment [45]. The authors of the MirrARbilitation system showed that their application is more efficient than traditional

rehabilitation methods because it improves user engagement and exercises performance outcomes. But the target population of these systems is only the patients after stroke and mastectomy for their arm movement exercises. However, due to the complexity and high cost of the AR Sleeve system, it can be used in rehabilitation gyms with multiple and concurrent therapeutic sessions.

Dementia is an incurable neurological illness that causes memory loss, anxiety, agitation, depression, and other neuropsychiatric symptoms, as well as a detrimental influence on the cognitive, emotional, and physical capacities of those who suffer from it [85]. Daily activities are tough for caregivers and people with Alzheimer's disease. AR approaches have been used to generate important studies. Quintana and Favela [25] used AR markers to insert reminders for completing a task [30]. Using HoloLens, an AR system was created to evaluate the beginning of Alzheimer's disease at an early stage. The symptoms that appear to be linked to early memory loss, particularly spatial memory, are the most critical features of early AD diagnoses. A game environment incorporates the capacity to store and recover the memory of a specific event involving an association between things such as the location and the object attributes [32]. However, such apps challenge the spatial intelligence of the patients with already impaired brains. Moreover, as such patients have compromised memory, they may not recall the steps and process to move forward in the application.

According to the researchers, a variety of physical activity therapy, such as aerobic exercise, resistance training, yoga, and dancing, may help patients with Parkinson's disease (PD). Dance's pleasurable aspect also elicits positive emotional responses, gives a means of communication and expression, and encourages frequent attendance at dance courses. MTG (Moving Through Glass) is a Google Glass application that acts as a portable, continuous extension of the device. It projects MTG films of various activities into the wearer's natural environment [19]. People with Parkinson's illness may benefit from AR-based therapies like MTG because they make dancing more accessible and adherent. Although these researchers digitalized the MTG and tested it, but the patient's sample size is comparatively small and no significant improvement has been observed as compared to the traditional therapy.

This research has been conducted to provide the synthesis of AR applications in the field of neurology. It poses a solution to the challenges faced by the patients suffering from neurological disorders. The novelty of this study is that it provides a guideline to design and develop applications used in neurology based on the challenges and gaps identified from the previous work. A taxonomy has also been proposed to present the classification of various aspects of AR applications in neurology. Moreover, this work presents a sub-system division of the physical therapy based applications and provides a layered architecture especially designed for neurological disorders considering the identified challenges.

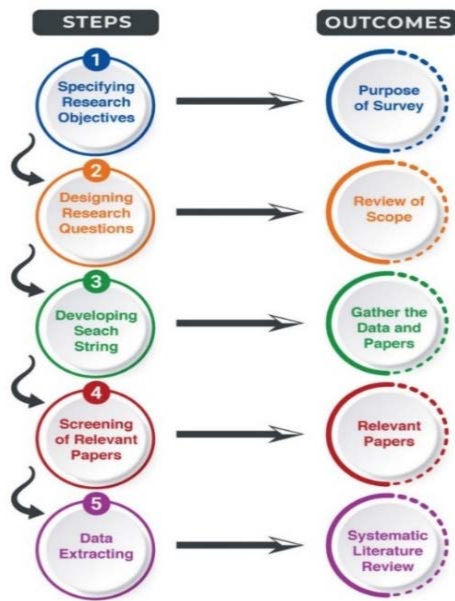


FIGURE 1. SLR process model.

TABLE 1. RQ and major motivations.

	Research Question	Major Motivation
RQ1	What is the scope of AR in terms of its uses for healthcare workers and the patients suffering from recognized neurological disorders?	To investigate how AR is being used in assistance and the treatment in neurology.
RQ2	What types of different neurological disorders are being treated using AR applications?	To find what type of neurological disorders (CNS, Brain) the AR applications mostly target.
RQ3	What effects do these AR systems have in terms of long/short term goal achievement for patients with recognized neurological disorders?	To examine influence of AR systems on improving patient's quality of life and performing their day-to-day tasks.

III. RESEARCH METHODOLOGY

Medical Science has extensively enhanced over the past span with major contributions coming from the introduction of technology as part of the diagnosis and treatment process. Newer fields in information technology such as AR have significantly improved quality of life (QoL). One aspect of medical science that requires a lot of visualization is neurology, a branch of medicine dealing with disorders of the nervous system. AR systems have made a stride in both diagnosis, prognosis, and treatment of diseases related to CNS and brain.

The research methodology chosen for this study is SLR. Its main goal is to evaluate how AR has influenced the rehabilitation and treatment of neurological disorders. The research methodology used for this study is shown in figure 1, which is the combination of the research methodologies in previous works [2], [3].

After defining the research objectives and formulating the research questions, search string is defined and run in popular

databases to collect relevant researches. Data collected has been refined by applying the devised inclusion/exclusion criteria.

A. RESEARCH OBJECTIVES (RO)

The main objective of this research is to examine the use of AR as either diagnostic or treatment/therapy or assistance tool for neurological disorders. The objective of conducting this work is divided into sub-objectives listed below:

RO1: Identify the contributions of AR technology in the journey of patients suffering from neurological disorders.

RO2: Identify the classifications of neurological disorder where AR systems have been used in the patient journey.

RO3: Identify the effectiveness of AR systems in a patient's lifespan.

B. RESEARCH QUESTIONS (RQ)

In order to meet the defined research objectives, the research questions were formulated, which are listed in table 1 along with the respective motivation behind formulating each question.

C. SEARCH SCHEME

The fundamental part of an SLR is the formulation of a search plan to effectively determine and gather relevant articles in the selected field. This process involves the narrative of a search string, all the literature resources that are used to apply the search, and the segregation (inclusion/exclusion) plan to get the most related papers out of the identified records.

1) SEARCH STRING

To collect relevant research, and work it is important to search the right way. To find related work, the searching methodology has been divided into three parts: disorder search, string search with disorder keyword, and general string search without the specific disorder. The first part includes finding the most common neurological disorders with either a diagnosis or treatment plans. This includes searching for the recognized medical disorder that is common in all parts of the world. This search has been done on search engines and online medical databases and websites like WebMD. This provided a list of neurological disorders that are used in the second part using a citation search engine to find previous literature ranging from January 2009 (initial phases of AR/VR technology) to April 2022.

The journals have been picked from IEEE Xplore, Google Scholar, Science Direct, ACM, PubMed, Springer, and similar. The search string was built in a similar format that works on a typical search bar where a neurological disorder was placed with Augmented Reality in the double quotation. For some search strings with a disorder that has no cure therapy keywords such as "Activity", "rehabilitation", and "therapy" were also searched. In the third part, a standalone

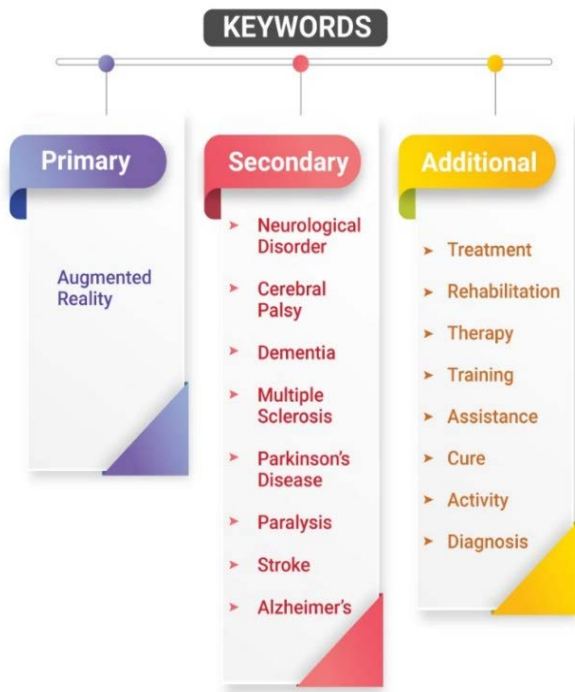


FIGURE 2. Search string keywords.

search has been done in the same place with general words such as “neurological disorder AND augmented reality”.

Multiple combinations of primary, secondary, and additional keywords shown in figure 2 were created using logical “AND”, “OR” and “NOT” boolean operators. The primary keywords were used as identifiers to limit the search results to those that were relevant to this investigation. Secondary and additional keywords were effective in summarizing the search results to find publications that were more closely related to this research.

Keywords with their abbreviations used to formulate the search string are the following:

Augmented Reality (AR), Neurological Disorder (ND), Cerebral Palsy (CP), Parkinson’s Disease (PD), Stroke (S), Multiple Sclerosis (MS), Dementia (D), Alzheimer’s Disease (AD)

The following equation describes the composition of search string.

$$R = \forall[(AR) \wedge (ND \vee CP \vee D \vee MS \vee PD \vee AD \vee S)] \tag{1}$$

In the equation 1:

R = Results obtain from the search string

\forall = for all

\vee = OR operator

\wedge = AND operator

The generic form of the search string using the above-mentioned keywords is:

TABLE 2. Search string.

Database	Search Query	Filters Applied
IEEE Xplore	("Document Title": Augmented Reality) AND ("All Metadata":Neurological Disorder) OR ("All Metadata":Cerebral Palsy) OR ("All Metadata":Dementia) OR ("All Metadata":Multiple Sclerosis) OR ("All Metadata":Parkinson’s Disease) OR ("All Metadata":Alzheimer’s Disease) OR ("All Metadata":Stroke)	2009-2022
Google Scholar	("Augmented Reality") AND ("Neurological Disorder" OR "Cerebral Palsy" OR Dementia OR "Multiple Sclerosis" OR Parkinson" OR "Alzheimer" OR "Stroke")	2009-2022
Science Direct	Augmented Reality AND ("Neurological Disorder" OR "Cerebral Palsy" OR Dementia OR "Multiple Sclerosis" OR Parkinson" OR "Alzheimer" OR "Stroke")	2012-2022
ACM Journal	[Title: "augmented reality"] AND [[All: "neurological disorder"] OR [All: "cerebral palsy"] OR [All: "dementia"] OR [All: "multiple sclerosis"] OR [All: "parkinson’s disease"] OR [All: "alzheimer’s disease"] OR [All: "stroke"]]	2012-2022
PubMed	(((((Augmented Reality) AND (Neurological Disorder)) OR (Cerebral Palsy)) OR (Dementia)) OR (Multiple Sclerosis)) OR (Parkinson’s Disease)) OR (Alzheimer’s Disease)) OR (Stroke)	2012-2022
Springer	Augmented Reality AND (Neurological Disorder OR Cerebral Palsy OR Dementia OR Multiple Sclerosis OR Parkinson’s Disease OR Alzheimer’s Disease OR Stroke)	2012-2022
Scopus	“Augmented Reality” AND “Neurological Disorder” OR “Cerebral Palsy” OR “Dementia” OR “Multiple Sclerosis” OR “Parkinson’s Disease” OR “Alzheimer’s Disease” OR “Stroke”	2012-2022

((“Augmented Reality”) AND (“Neurological Disorder” OR “Cerebral Palsy” OR “Dementia” OR “Multiple Sclerosis” OR “Parkinson’s Disease” OR “Alzheimer’s Disease” OR “Stroke”))

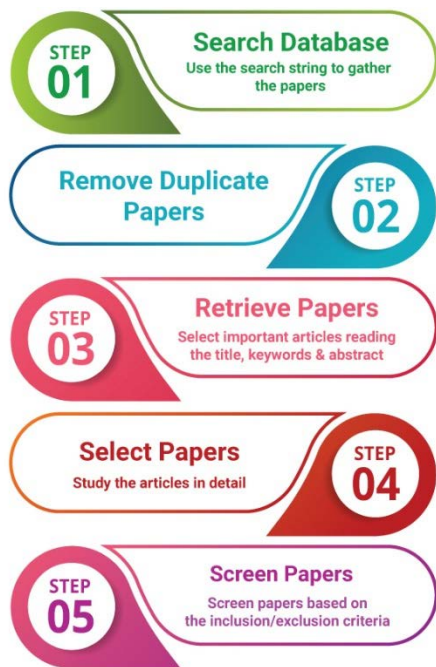


FIGURE 3. Selection procedure.

2) LITERATURE RESOURCES

The research articles collected for this study have been collected from the credible databases described below:

1. ACM Digital Library
2. Springer
3. PubMed
4. Science Direct
5. Google Scholar
6. IEEE Xplore
7. Scopus

Table 2 displays the search strings used to extract the relevant publications from the above-mentioned databases and the applied filters. The papers extracted from these databases were used to conduct the study after filtering through multiple techniques.

3) INCLUSION AND EXCLUSION CRITERIA

The criteria set to shortlist the papers are following

a: INCLUSION CRITERIA

- IC 1) Paper focusing on the use of AR in main capacity.
- IC 2) Paper mentioning recognized neurological disorders.
- IC 3) Paper focusing either on diagnosis, treatment, or assistance of the neurological disorder.

b: EXCLUSION CRITERIA

EC 1) Paper in which AR is not being used in the main capacity or the work doesn't demonstrate AR as a tool for the treatment of the neurological disorder.

EC 2) Paper in which augmented reality and recognized neurological disorder are not mentioned explicitly.

EC 3) Paper that is not written in English.

EC 4) Paper that is re-published.

4) SELECTION OF RELEVANT PAPERS

This SLR has been conducted based on the papers published between January 2009 and April 2022. Numerous articles were gathered during the primary search but some of them were related to the study and some were not. The papers were then filtered following the process shown in figure 3 [58].

Initially, the papers were filtered out based on the titles and abstracts. The abstracts have been analyzed carefully to determine relevance to the research questions and the main objective of this research.

The literature screening was a two-step process. In the first step, all the literature has been scanned to see if keywords such as neurological disorder and AR are present in the title. The journal/conference in which papers were published to ensure the literature title matches context-wise. Out of around 135 selected papers, the first step of screening resulted in around 47 papers. After the initial round, the abstract of the paper has been carefully read and detailed the paper using the technique defined by Keshav [4].

In figure 4, the PRISMA technique used for literature searching and selection is presented, together with the number of articles found at each stage. The screening has been done twice, in the first cycle, 82 related papers were gathered that were shortlisted to 21 papers after passing through the inclusion and exclusion criteria. In the second round, 29 papers were shortlisted from a total of 108 articles. So, this study provides the review of 47 papers in total. As the search results were based on keywords that may have alternate meanings in different scenarios; hence, a careful screening of papers was carried to shortlist the finalized set of papers for review.

5) QUALITY ASSESSMENT CRITERIA

To establish a ranking system, we look at the different goals each paper presented. For that purpose, point system has been used, which is a known metric for ranking literature. Three basic ideas have been developed and if the ideas have been accomplished in the said literature, then a (+1) point was awarded to the paper. Moreover, if the paper was published in a CORE A or greater conference journal with a significant impact factor then it would be awarded an additional (+1). Here are the general ideas

a: INTERNAL CRITERIA

- 1) Does the study claim to present a novel idea of using AR for treating or diagnosing neurological disorders? If so, the paper is given a +1 Rank.
- 2) Does the paper pose significant results in achieving the goals set at the start of the research? If so, the paper is given a +1 rank.
- 3) Does the paper offer a comparison to traditional techniques present empirical evidence for success in

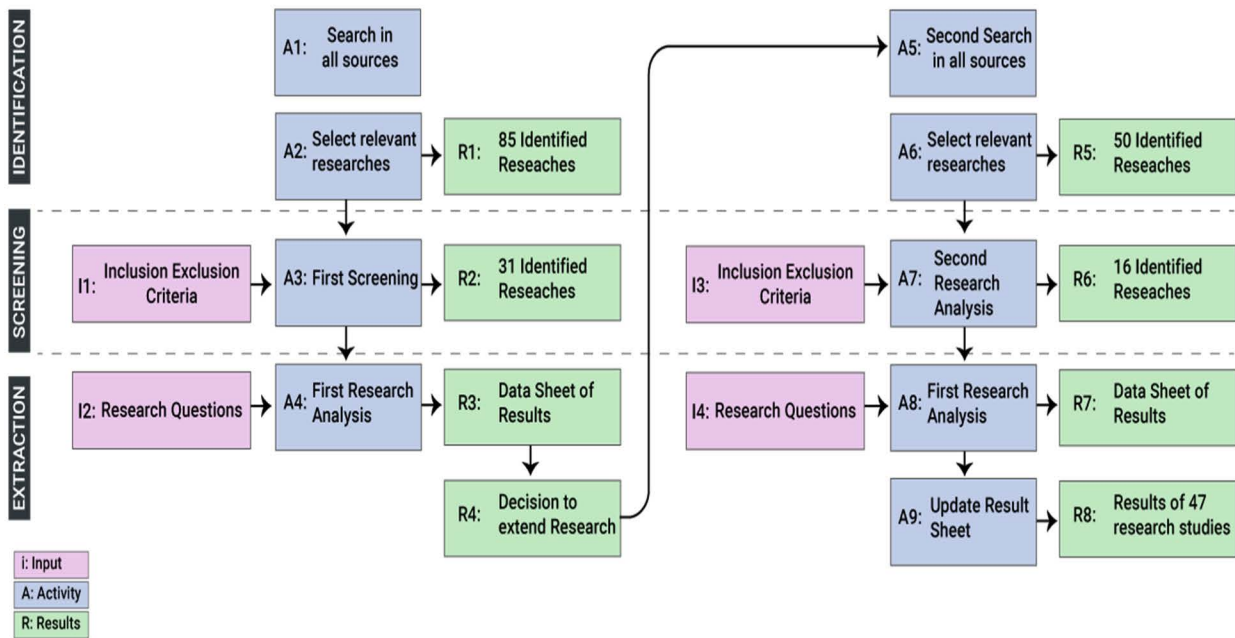


FIGURE 4. PRISMA flow diagram.

assessment criteria (b)? The paper is given a +1 rank for achieving this

b: EXTERNAL CRITERIA

- 1) To measure the external quality based on the publication sources JCR and CORE

Based on the abstract section of literature collected, the papers have been carefully scanned to find relevant data if available for the given research question. If the paper mentioned a research question or provided information that paper was accepted even if it partially provided the resource. The paper provided the 3 phases of reading (a technique described in [4]). The analysis, evaluation, and result sections were scanned for more information and if that information matched the research question either partially or fully the literature was evaluated using assessment criteria.

This section piles up the consequences and presents a clear valuation of all screened papers. The main focus of this part is to discuss the quest concerns gathered via a defined seek string. Table 3 contains the description of the scores used to evaluate the selected articles and the comprehensive discussions to reply to all the research questions are in the last section.

D. DATA ANALYSIS

The papers were then assessed based on the defined criteria of assessment. All the articles were carefully investigated to figure out the research questions’ answers. The selected articles have been first classified and then a classification table i.e. table 4 is created, based on the following factors: publication channel and year, research type, empirical type,

major focus, assessment criteria, scope of AR, neurological disorders categories, and impact of AR assistance

The articles were assessed and scored using the previously stated scoring criteria (internal and external). Figure 5 shows a visual depiction of the rankings of the articles based on internal and external scores.

Each question to assess the internal criteria has been assigned 1 score. And question for the external criteria has been assigned 2 score, so the score has been calculated out of the 5. Papers having a total score of more than 2.5 have been ranked as high level, less than 2.5 have been ranked as low level, and 2.5 score is considered average ranking.

Only 14.8 % are scored as low, and 12.7% as average, according to the results of the whole review. The remaining 72.3% are rated higher than average.

Figure 6 depicts the number of articles published in either a journal or a conference each year. With the collected statistics, it can be clearly stated that AR technology took a boost since 2018, and most of the work has done in 2018 and 2019. 51% papers have been published in journals and 49% have been published in conferences.

- 1) RQ1) WHAT IS THE SCOPE OF AR IN TERMS OF ITS USES FOR HEALTHCARE WORKERS AND THE PATIENTS SUFFERING FROM RECOGNIZED NEUROLOGICAL DISORDERS?

AR technology has introduced a newer and interactive dimension to the treatment and therapy process by introducing senses that are often difficult to simulate. This allows the simulation of the brain and nervous system, which may not be possible with medication or traditional physical therapy. This also allows users to experience situations virtually, which

TABLE 3. Criteria to assess the quality.

Sr.	Assessment Criteria Questions	Expected Answers	Score
Internal Scoring Criteria			
1	Does the study claim to present a novel idea of using AR for treating or diagnosing neurological disorders?	a. Yes	a. 1
		b. Partial	b. 0.5
		c. No	c. 0
2	Does the paper achieve significant results in achieving the goals set at the start of the research?	a. Yes	a. 1
		b. Partial	b. 0.5
		c. No	c. 0
3	Does the paper compare to traditional techniques that present empirical evidence for success in assessment criteria (2)?	a. Yes	a. 1
		b. Partial	b. 0.5
		c. No	c. 0
External Scoring Criteria			
4	A study published in JCR listed ranked journal	a. Q1 rank	a. 2
		b. Q2 rank	b. 1.5
		c. Q3/Q4 rank	c. 1
		d. No Rank	d. 0.5
5	Source-based ranking for The conference, Workshop, Proceedings and Symposia	a. CORE A rank	a. 2
		b. CORE B rank	b. 1.5
		c. CORE C rank	c. 1
		d. No CORE rank	d. 0.5

may be dangerous or inconceivable. This infusion of AR let the healthcare workers/doctors to treat patients through allopathic medicine and improve their progress through sensory training using AR. [8] is research that uses AR to simulate special disorders and measure the impact using cardio-vascular vitals such as heart rate. Similarly, more and more research is observed for physical health therapy where exergames have been developed for rehabilitation of patients and results are collected based on physical movements done during the serious game. An approach in [15] focused on the gait and posture of participants. Research such as [15] also shows that gait rehabilitation using a mounted AR headset with a new algorithmic approach called HoloLens can be beneficial for patients especially kids with cerebral palsy (CP). Similarly, gait biomechanics and position control are being measured and their effect is being calculated using AR headed

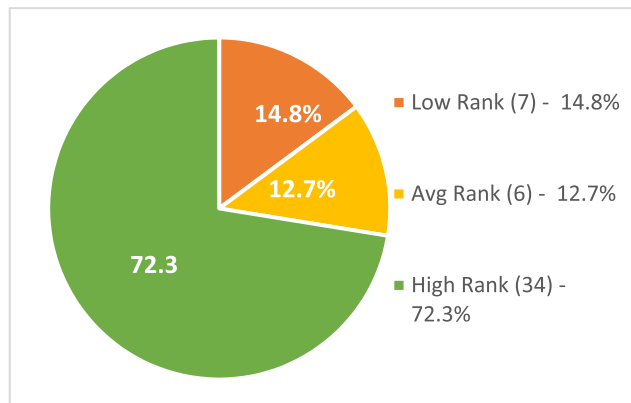


FIGURE 5. Score based articles ranking.

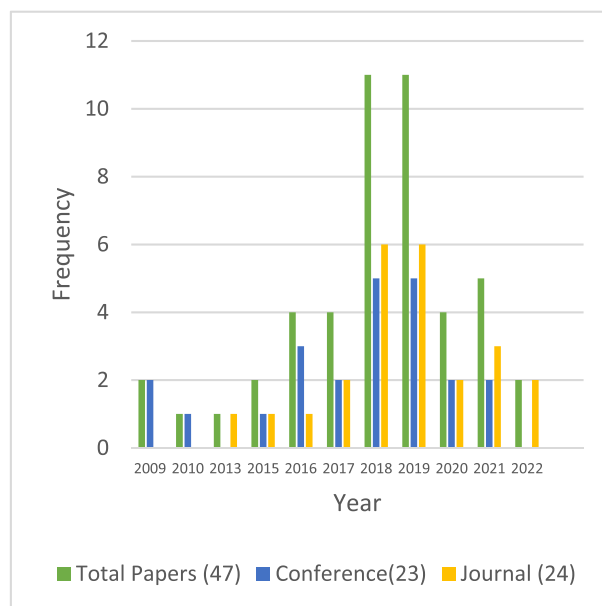


FIGURE 6. Annual frequency of publication.

mounted device for movements such as walking in research done in [24]. This allowed the researcher to identify different gait positions than expected, which may result in degradation of gait movement treatment overall for users. In some cases of MS patients, physical therapy might also be needed to slow down the effect of the disease. The application has been designed to treat balance and rehabilitate MS patients who experience balance issues using a home-based VR/AR system and infused daily tasks such as multi-tasking and obstacle negotiation [22].

Mental health therapy such as Neurofeedback Therapy for the patients suffering from ADHD has shown a significant improvement in the treatment’s efficacy. This disease usually effects the younger individuals and cause them to make impulsive decisions or decrease their success rate in all the aspects of life. The usual treatment process of this disease is deadly that causes patients to lose motivation but with the help of AR technology, the whole process has been made interesting by designing interactive graphical

TABLE 4. Classification and quality assessment.

Sr.	Publication		Classification					Internal Scoring			External Scoring	Total Score (5)	Ref. No
	Channel	Year	Major Focus	Scope of AR	Neurological Disorder Category	Disorder Name	AR Assistance's Impact	(a)	(b)	(c)	(d)	Score	
1	Journal	2021	An algorithm named HoloStep calculated spatiotemporal gait constraints using an augmented reality headset (HoloLens).	Physical Health Rehab	Movement Disorder	Cerebral Palsy	Long Term	1	0.5	1	1.5	4	[15]
2	Conference	2018	The framework cARe was developed to guide the manual process using localized visual and audio cues rendered by the HMD.	Patient's Task Assistance	Degenerative	Dementia	Short Term	1	1	0	2	4	[9]
3	Journal	2020	Post stroke AR rehabilitation	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	0.5	0	1.5	3	[12]
4	Journal	2021	Determined the effectiveness of AR applications used by patients to reduce the fear and pain of injections	Patient's Task Assistance	Degenerative	Multiple Sclerosis	Short Term	0	0.5	1	1.5	3	[65]
5	Conference	2019	Development of smartphone-based AR Rehab System for stroke rehabilitation	Physical Health Rehab	Movement Disorder	Stroke	Long Term	0.5	0.5	1	0.5	2.5	[14]
6	Journal	2018	The game is used as a supplement to traditional treatments, not as an alternative	Physical Health Rehab	Movement Disorder	Cerebral Palsy	Long Term	0.5	0.5	0.5	1.5	3	[46]
7	Journal	2018	Usage of AR and VR as intellectual assistances for people with dementia, especially in the initial stages of illness	Patient's Task Assistance	Degenerative	Dementia	Short Term	0	1	0	0.5	1.5	[47]
8	Conference	2019	3D visualization of the organs to the patients	Healthcare Worker Assistance	-	-	Short Term	1	0.5	0	0.5	2	[16]
9	Conference	2017	Investigated the capabilities of AR games that enable an objective valuation of upper limb motor dysfunction using hands-free interactions.	Physical Health Rehab	Movement Disorder	Stroke	Long Term	0.5	0.5	1	2	4	[17]
10	Conference	2017	Created a series of different playtest games to assess upper limb motor dysfunction	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	0.5	0.5	2	4	[18]

TABLE 4. (Continued.) Classification and quality assessment.

11	Journal	2020	Evaluated the feasibility, protection, and suitability of cell dance interventions and get an initial performance rating	Physical Health Rehab	Degenerative	Parkinson's Disease	Short Term	1	1	0	2	4	[19]
12	Journal	2016	Determined the predicted results of a system that is based on the AR system for stroke participants' upper-limb motor rehabilitation.	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	1	1	2	5	[49]
13	Journal	2019	Supported the idea that rehabilitation with new VR tools could have a positive impact on the outcome of MS patients	Physical Health Rehab	Degenerative	Multiple Sclerosis	Short Term	0	1	0	1.5	2	[22]
14	Journal	2019	Examined how AR is useful to support transphenoid surgery	Healthcare Worker Training	-	Pituitary Tumors	-	1	0.5	0.5	1.5	3.5	[23]
15	Journal	2019	Treadmill running using HMD devices for location control and gait biomechanical impact analysis	Physical Health Rehab	Movement Disorder	Stroke	Long-Term	0.5	0.5	0	2	3	[24]
16	Journal	2018	AR is used as cognitive assistance in individuals with dementia, especially in the early stages of illness	Patient's Task Assistance	Degenerative	Dementia	Short Term	0.5	1	0.5	1.5	3.5	[36]
17	Journal	2013	Described the Ambient aNnotation System (ANS), which aims to help people with AD and their caregivers	Patient's Task Assistance	Degenerative	Dementia	Short Term	1	0.5	0	1.5	3	[25]
18	Journal	2021	Targeting nursing school students, the use of AR has been tested in instructing medical professionals with a stroke valuation simulation developed for clinical education	Healthcare Worker Training	Movement Disorder	Stroke	Short Term	0.5	1	0.5	2	4	[35]
19	Journal	2017	AR in neurosurgery	Healthcare Worker Training	-	-	Short Term	1	1	1	2	5	[26]
20	Journal	2018	Patient-Tailored therapy based AR Games for Evaluating Upper Extremity motor deficiencies in movement disorders like stroke	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	1	0	2	4	[27]
21	Conference	2018	Presented a phone App that recognizes objects and people to assist patients in the early stages of Alzheimer's Disease	Patient's Task Assistance	Degenerative	Alzheimer's Disease	Short Term	1	0.5	0	2	3.5	[30]
22	Conference	2020	Developed AR-based gameplay for the recovery of patients with Parkinson's.	Physical Health Rehab	Degenerative	Parkinson's Disease	Long Term	1	0.5	0.5	0.5	2.5	[31]
23	Conference	2020	Engaged AR in the framework of a virtual telekinetic game to treat ADHD	Mental Health Rehab	Degenerative	Attention Deficit Hyperactivity Disorder (ADHD)	Long Term	1	0.5	0	2	3.5	[51]

TABLE 4. (Continued.) Classification and quality assessment.

24	Conference	2018	Mirror therapy as AR in the stroke treatment	Physical Health Rehab	Movement Disorder	Stroke	Long Term	0.5	0.5	0	0.5	1.5	[52]
25	Conference	2010	Rehabilitation prototypes development using available AR libraries	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	0.5	0	0.5	2	[53]
26	Conference	2009	Evaluated the progress of post-stroke patients using an AR BASED Rehabilitation system	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	0.5	0	0.5	2	[54]
27	Journal	2017	Design an app named Moving Through Glass: Dance therapy for Parkinson's Disease.	Physical Health Rehab	Degenerative	Parkinson's Disease	Short Term	1	1	1	2	5	[48]
28	Conference	2019	Designed a mobile phone AR exergaming system known as ARMove for upper and lower extremities stroke rehabilitation therapy	Physical Health Rehab	Movement Disorder	Paralysis/Stroke	Long Term	1	0.5	0	2	3.5	[56]
29	Conference	2016	Designed a rehab system based on AR technology, and played four Exergames set up on interaction, intelligence, and fun.	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	1	0	1	3	[57]
30	Conference	2018	Using the AR mobile technology converted a sit to stand game exercise into engaging meaningful play	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	0.5	0	1	2.5	[58]
31	Conference	2018	Provided a framework named cARe, to provide therapists with a holistic solution	Patient's Task Assistance	Degenerative	Dementia/Alzheimer's Disease	Short Term	1	1	0	2	4	[9]
32	Conference	2021	Designed an AR system named My Daily Routine (MDR), to help people suffering from dementia and their caretakers	Patient's Task Assistance	Degenerative	Dementia	Short Term	1	1	0	0.5	2.5	[60]
33	Conference	2016	Providing Home Based rehabilitation to the children with CP by designing an AR Exergames, that includes the MYO armband	Physical Health Rehab	Movement Disorder	Cerebral Palsy	Long Term	1	0.5	0.5	0.5	2.5	[61]
34	Conference	2021	AR-based mirror therapy system named as FaraPy, for Facial paralysis	Physical Health Rehab	Movement Disorder	Paralysis	Long Term	1	1	0.5	2	4.5	[62]
35	Journal	2019	Assisted patients in making tea with HoloLens	Patient's Task Assistance	Degenerative	Alzheimer's Disease	Short Term	1	1	1	2	5	[63]
36	Journal	2022	Determining the impact of AR intervention on upper limb therapy and range of movement in children with cerebral palsy	Physical Health Rehab	Movement Disorder	Cerebral Palsy	Long Term	0	1	1	2	4	[64]
37	Journal	2020	Using AR-based technology to reduce patients' injection anxiety and perceived pain for patients with MS	Patient's Task Assistance	Degenerative Disorder	Multiple Sclerosis	Short Term	1	1	0	1.5	3.5	[65]

TABLE 4. (Continued.) Classification and quality assessment.

38	Journal	2022	The influence of AR technology on the rehabilitation of lower and upper limb motion in stroke patients is the focus of this study.	Physical Health Rehab	Movement Disorder	Stroke	Long Term	0.5	1	1	1.5	4	[66]
39	Journal	2015	The patients used their intended arm movements to play the Fruit Ninja video game on both the AR and PC platforms.	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	1	1	2	5	[67]
40	Journal	2019	Soft HoloLens-based wearable AR application for shoulder rehabilitation	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	1	0.5	0.5	3	[68]
41	Conference	2015	Presented a novel approach named SleeveAR, to address multimodal feedback strategies	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	0.5	0	0.5	2	[69]
42	Conference	2016	SleeveAR is an innovative technique for real-time feedback that uses many projection surfaces to create effective visuals.	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	1	0	2	4	[70]
43	Journal	2009	The framework's and its subsystems' underlying architecture make it very convenient for stroke sufferers and their caretakers.	Physical Health Rehab	Movement Disorder	Stroke	Long Term	1	0.5	0	2	3.5	[71]
44	Journal	2018	Experimented to see how dementia patients can perform several activities in an AR environment utilizing a range of human-computer interaction strategies.	Patient's Task Assistance	Degenerative	Dementia	Short Term	0.5	1	1	0.5	3	[72]
45	Conference	2019	To assist dementia patients, researchers built a projection-based AR system robot that can span 360 ° of surroundings.	Patient's Task Assistance	Degenerative	Dementia	Short Term	1	0.5	0	2	3.5	[59]
46	Journal	2019	Instead of a unidirectional PAR system, researchers developed a bidirectional projection-based augmented (PAR) system for the elderly.	Patient's Task Assistance	Degenerative	Dementia or Alzheimer's Disease	Short Term	0.5	0.5	1	2	4	[55]
47	Conference	2019	Presented the continued development of a HoloLens-based AR system for diagnosing Alzheimer's Disease at an early stage.	Healthcare Worker Training	Degenerative	Alzheimer's Disease	Short Term	0.5	1	0	2	3.5	[10]

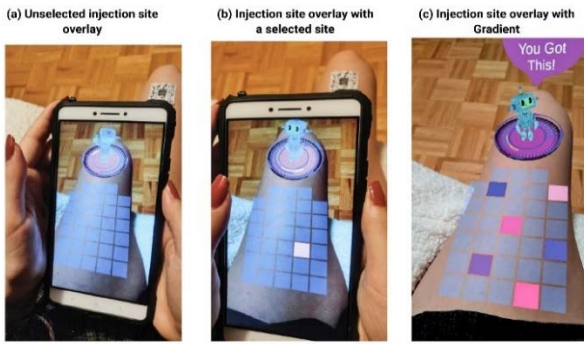


FIGURE 7. MSease, an AR application to aid patients diagnosed with multiple sclerosis.

interfaces or games and providing the feedback of patient’s brainwave activity, that is taken via [51]. This kind of therapy has helped them a lot to improve their cognitive ability.

AR has also been helpful in the training of the doctors especially when it comes to the sensitive and complex surgeries like neurosurgery or transsphenoid surgery. An AR system has been developed for the practice of the healthcare workers to perform neurosurgery. With the help of this system, the doctors are trained to perform the surgery on the augmented robot and in result of this practice, lower malpractice ratio has been observed [26].

AR systems help patients to perform their everyday tasks to improve their living [65]. In case of diseases like dementia, where patient’s memory is worsen day-by-day, AR applications assist them to perform an activity/task like making tea [25], or to recognize objects, for example, AR systems have been observed where intellectually impaired individuals get an alert signal to stay away from hot objects [22].

Not only does the system provide rehab for degenerative diseases such as MS and PD, but for healthcare workers as well. Figure 7 presents an MSease application to aid the patients diagnosed with MS [65]. These applications show a guided injection delivery using AR that let MS patients or their nurses visualize injection sites by an overlaid AR grid.

The researchers developed an application [16] where AR was used to transform medical records into 3D organs, which gave an in-depth idea of medical history to patients allowing them to visualize their organs.

Figure 8 presents the stats of the infusion of AR in patients’ or healthcare workers’ life. From the statistics obtained after evaluating the selected papers, it is revealed that mostly AR technology has been used in physical health therapy and for the guidance of patients in day-to-day tasks.

2) RQ2. WHAT TYPES OF DIFFERENT NEUROLOGICAL DISORDERS ARE BEING TREATED USING AR APPLICATIONS?

Over 10 years different types of research has been collected and analyzed where two recurring patterns have been

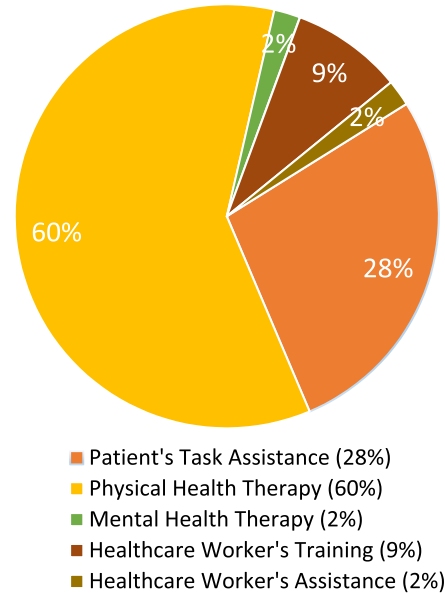


FIGURE 8. Scope of AR.

observed in which the AR applications have been provided as a treatment alternative to traditional medicine processes. AR applications are either mostly used for treating movement disorders where patients are struggling with limbic movement, balance, or coordination of hand-eye movements. Another pattern is observed where AR application is being used to maintain the capabilities of the brain to think and memorize, especially in parts of the cerebrum. Disorder or degenerative diseases where a person loses capability and gets slower while using interactive games/activities using AR.

AR has been used for the treatment of motor diseases such as CP using AR applications that help do motion coupled with a physical device such as a treadmill [15]. Level 3 patients of GMFCS (Gross Motor Function Classification System) have been rehabbed with AR-mounted headsets for movement disorders [24]. Research in [17] developed an AR application for hand movements such as finger tapping gestures with healthy people as a control group and patients with PD and cerebrovascular accident (CVA). MS and PD already treated with AR applications has been observed such as in [29]. Similarly, in [18] AR being used to treat patients who have suffered paralysis due to stroke and PD by asking them to perform hand movements. Similarly, PD patients were provided with paths such as circular paths using AR [31] to improve the motor function of the nervous system. Around 20 patients with idiopathic PD were part of research that helped do physical activity or ‘class’ where participants were required to do movement such as boxing/swimming using Google glass in research conducted in [19]. More movement exercises were done in [27] for patients with stroke disabilities. While some applications focused on only movement disorders some applications also focused on the disorder that affected brain functionality. In [14] research was done where

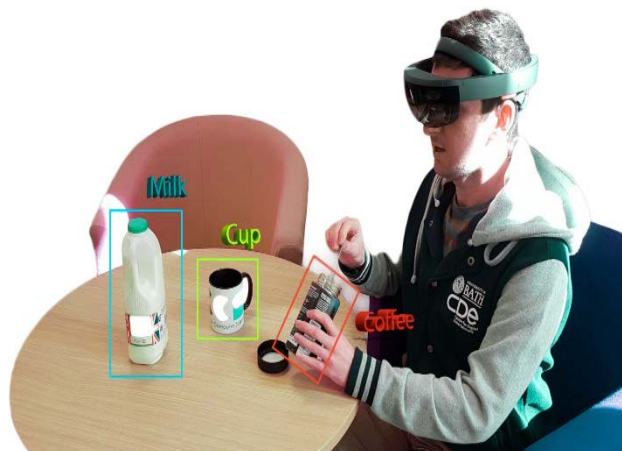


FIGURE 9. AR System for Alzheimer’s patient.

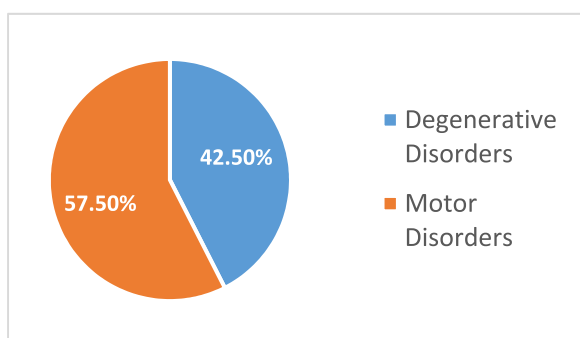


FIGURE 10. Neurological disorder’s classifications frequency.

stroke patients were rehabilitated using AR applications that not only worked on improving motor skills but also on mental state using interactive color-based AR games using mobile devices. MR applications have been used by doctors to identify stroke patients and their current mental state in clinical training settings [35]. AR has been used for the rehabilitation of stroke patients. [12] mentioned various research where applications using shapes and color with help of gamification to replace standard medical processes such as physiotherapy to improve critical thinking.

Another classification of neurological disorder is degenerative where the function or structure of the damaged tissues or organs worsens over time. Alzheimer’s disease and dementia are also key neurological disorders have that treated with AR-based applications where patients experience progressive memory loss [40]. [25] showed patient use case of AR using a mobile application, which could be a guidance tool for the patient that suffers from Alzheimer’s. The application would display safety messages on the environment with AR + camera input to warn patients of hot applications such as stove/coffee makers. It also provided tags for patients to recognize different items in their surroundings and gave valuable instruction that will help them perform day-to-day tasks as shown in figure 9 [25] where an AR system is helping a dementia patient to make coffee.

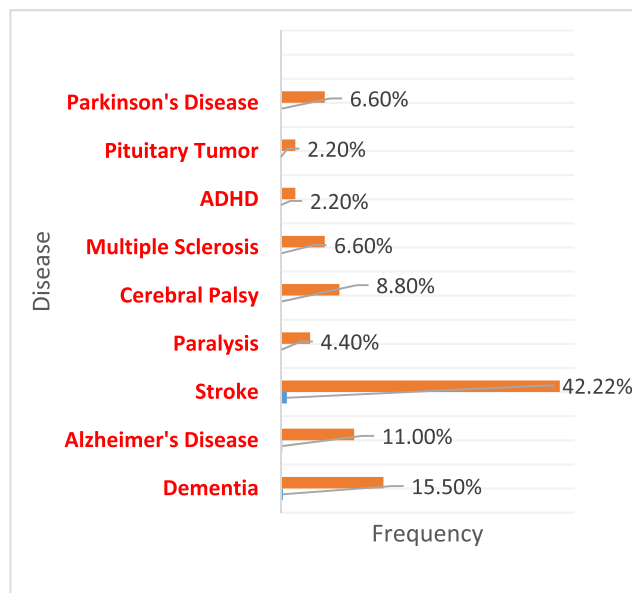


FIGURE 11. Statistics of the neurological diseases treated by AR.

[30] provided a patient and caregiver with an AR-based application to keep track of progress and perform the daily task using AR assistance coupled with smartphone technology. It was tested with patients with Alzheimer’s.

Figure 10 shows the statistics of the types of neurological disorders that are mostly being catered by AR technology. By carefully evaluating the research papers, it has been observed that AR technology has been used for degenerative disorders more than motor disorders.

Figure 11 presents the frequency of diseases that are being treated by AR technology. It has been observed after evaluating the selected papers that mostly AR systems have been used for the rehabilitation of the stroke patients.

In all those disorders, AR has been infused in various capacities. From the results, it is clear that AR systems are very helpful for stroke patients due to the of use physical health therapy for their treatment. Although AR has enhanced the quality of life of the patients suffering from neurological disorders, yet there is a need to increase the use of AR in for the diseases like pituitary tumors and ADHD.

3) RQ3. WHAT EFFECTS DO THESE AR SYSTEMS HAVE IN TERMS OF LONG/SHORT TERM GOAL ACHIEVEMENT FOR PATIENTS WITH RECOGNIZED NEUROLOGICAL DISORDERS? AR applications have a wide variety of use cases and most of the applications focus on rehab of the users. As shown in RQ2 the two different targets are motor movements and mental ability that AR application tries to improve on. Different research is done to examine the effectiveness of AR applications. A study [28] presented the use of social robots and AR to assist the display for patients with dementia. The research showed an increase in contextual interactions and usage. Similarly, a work [9] showed AR-based patient support system called ‘cARe’ was introduced that helped

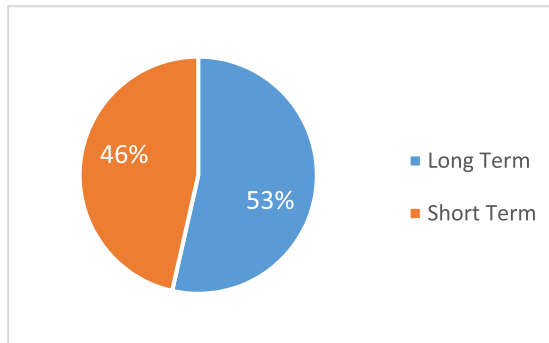


FIGURE 12. Statistics of impact of AR assistance.

dementia patients and caregivers maintain a good balance and allowed patients to perform day-to-day tasks longer without the need for supervision. [9] showed various research with AR/VR applications that have proved beneficial for patients with dementia.

To understand the goal achievements for AR apps, it is important to understand how much impact an app has with relevance to the time used. Hence, time spent on the app has importance in the evaluation of the patients' condition. To understand this better, goal achievement has been divided based on long-term and short-term improvement. The difference between long-term and short-term goal achievement is that the long-term goal achievement refers to improvement in a patient's ability to overcome what was previously hampered by his/her disease with time spent on the application. This includes multiple months or years of using AR applications. In contrast to that, some AR applications show short-term goal achievements by posing improvements in patients' quality of life. This includes the patient's guidance application where the patient spends a very small fraction of time using the application as immediate goal achievement. This goal is achieved usually is in the form of day-to-day tasks and has no direct impact on the improvement of patients' diseases.

Figure 12 presents the impact ratio of AR technology, which shows that use of AR leaves more long-term impact than short-term on patient's journey. It outlines applications that provide healthcare workers with patient movement data within a home environment allowing better clinical decision-making. [26] presents a list of research that use reality in the form of augmented and virtual reality to improve neurosurgery outcomes. Here are some examples, such as the microscope-based AR system, which has proven to be particularly useful in neurovascular surgery by improving the placement of craniotomy and the opening of the dura mater. This allows healthcare workers to maintain a low malpractice rate and improve patient care.

This allows healthcare workers to maintain a low malpractice rate and improve patient care. In [23] better surgical process has been provided to reduce stress for patient and surgeon while performing neurosurgery by allowing better visualization. This greatly improves the surgery success rate

and decreases complications. A research [36] provides smart visualization for tumors in the brain using smart that gave better accuracy than medical 2D imaging disorders, which often need AR application assistance. This has also been experienced by [20] where the 2D model was considered better by participants than the 3D model.

IV. DISCUSSION AND IMPLICATIONS

A taxonomy has been proposed in figure 13 after carefully evaluating the collected papers, and concluded that AR systems in neurology are based on three main aspects. The first aspect is the scope of an AR system that describes a purpose and the user system is intended. Two users are predominantly using AR systems in neurology. The first category of the user is patients or people suffering from a neurological disorder. To support their treatment, there are two types of activities that AR application performs. The first one is rehabilitation that includes all types of therapies of the patients. Therapies may be physical or mental. These applications try to directly impact the users' progress during the patient's life cycle and mitigate the effects of disease. Physical therapy refers to the movement and exercises that a patient does with the help of AR system to improve his deterioration of disease or gain back the abilities of their muscles, strength, balance, and movement. This is the most common type of AR system found in neurology where interactive exergames are used to treat patients. The second type of therapy is mental therapy, which targets the user's cognitive ability to improve his thinking, understanding, and reflexes.

This may include memory exercises, attention exercises, and cognitive ability testing. These types of AR systems are rare in neurology as observed that such patients often have limited cognitive ability to understand the setup and operate AR systems.

While many systems are trying to rehabilitate users. There is also a category of task assistance systems designed for patients to perform daily activities that are hampered by their disease. Those activities may not directly relate to symptoms caused by the disorder but have an influence on the patient's quality of life.

Some AR systems help users to perform menial tasks such as making food, taking medicine, and assisting them in performing day-to-day activities while some systems help users to navigate social conditions such as cautioning them of dangerous objects in the environment (e.g. Alzheimer's patients being cautioned to stay away from the oven or hot objects).

The other type of users of an AR system in neurology is healthcare workers such as doctors, paramedical staff, surgeons, and personal healthcare providers. These systems help doctors in the field of neurology and improve their ability to diagnose and treat patients. This category includes general-purpose systems that help healthcare workers from training to diagnose disorders using AR-based 3D models and help them visualize a patient's medical report in a more interactive environment. There are also surgery simulation

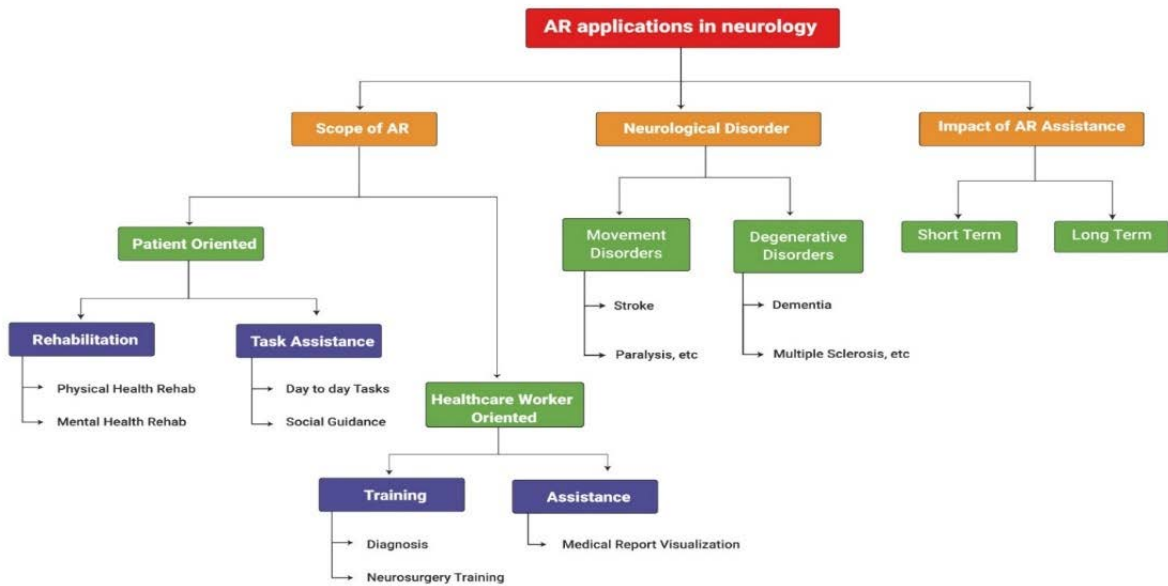


FIGURE 13. Proposed taxonomy of AR applications in neurology.

AR systems that help neurosurgeons practice complex surgeries before performing them on real patients. There are also a few AR systems that help healthcare workers through passive medical record gathering and helping them visualize patients’ progress.

The second aspect is the classification of neurological disorders, which are being treated using the AR system. First and the most common type of neurological disorder, which is prevalent in these AR systems are “movement disorders”, which refer to diseases that impact a user’s mobility and motor functionality. Such disorders may present users with challenges of loss of limb movement. These disorders are mostly treated using physical therapy. Hence, these are the most common type of AR systems that have been observed in this search.

Another type of neurological disorder that has been observed is degenerative disorders. These disorders usually get worse over time for the patient and the only way to combat them is to decrease their rate of progression. PD, Alzheimer’s, and some cases of dementia are examples of these disorders. These disorders are usually not directly improvable and the most common systems are assistive systems that are designed for patients to improve their quality of life and maintain their ability to be independent in life.

The third aspect of AR systems in neurology is their impact on achieving goals such as improvement in the patient disease. These goals may be short-term in nature, which means they are objectively small and require less period to achieve. The most common of these goals are day-to-day activities that require less time from the user and provide goal achievement. Other types of goals are long-term in nature. These are usually rehabilitation activities that require a large span of time and are usually directly linked to the

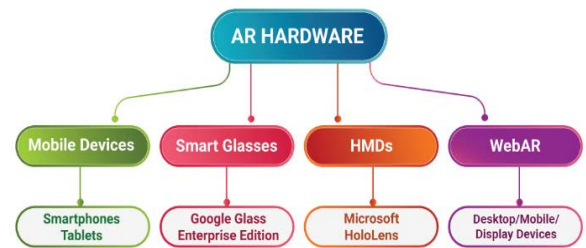


FIGURE 14. AR hardware.

patient’s system. This includes muscle activities/exergames that last for weeks up to months. This is the most common type of goal setting in the AR system observed in our research.

A. CLASSIFICATION OF AR SYSTEMS FOR NEUROLOGICAL DISORDER

Table 5 summarizes the AR-based system for neurological disorders. These systems contain different types of meaningful plays to rehab the patients, such as apps to help in the therapy or exercise and also for assisting the patients/healthcare workers. As AR is a field that augments the real-world experience accessible to all, the implementation also requires AR to be universally available, which means AR must not require specific hardware to run. Whatever device runs, the AR must be powerful enough to render 3D models and have enough sensors to be interactive. This means that today, common smartphones, tablets, and handheld devices can run AR applications [39]. The most common devices used in AR systems include handheld devices such as smartphones/tablets, smart glasses [33], HMD [13], and desktop PCs as shown in figure 14.

TABLE 5. AR Systems for neurological disorder.

Neurological Disorder Type	Disease	AR System	System's Technique	System's Goals	AR Technology	AR Interface	Ref.
Movement Disorders	Stroke	AR Move	Rehab (exergames like kickball, trial path, hand prints, pizza cutter)	Hamstring movement/ arm flexion/bilateral coordination	Markerless	Smartphone	[56]
		NZ Fauna AR	Rehab (exergames where users sits to pick a berry and stands to hit the kiwi)	Sit-to-stand exercise	Markerless	Smartphone	[58]
		Wearable AR Application	Rehab (exergames)	Shoulder rehabilitation	Markerless AR	HoloLens	[68]
		AR Rehab	Rehab Non-game based (shelf exercise/cup exercise) Game-based (cannonball, air hockey, and block)	Grasp-and-release tasks/ hand movement/ wrist movement	Marker-Based AR	HMD	[71]
		Augmented Reflection Technology (Art) System	Rehab (activity)	Upper limb training depends on the severity and level of their impairment.	Markerless AR	Display Devices	[76]
		AR System	Rehab (exergames)	Wrist, hand, or shoulder flexion-extension	Markerless AR	HMD	[75]
	Paralysis	SleeveAR	Rehab	Provides feedback to aid and guide during rehabilitation exercises.	Markerless AR	HoloLens	[69]
		A-Based Fruit Ninja Game	Rehab (exergames)	Hand/shoulder movement	Marker-Based AR	HMD	[74]
		KINVIS	Therapy (clinical trial)	Shoulder/arm/wrist/ hand movement	Markerless AR	Smartphones/ Tablets	[77]
		FaraPy	AR Mirror therapy system	Facial exercise	Markerless AR	Smartphones/ Tablets	[62]
	Cerebral Palsy	ARPC System (AR-Based Postural Control)	Therapy	Balance and gait movement /posture control	Markerless AR	HMD	[78]
		-	Rehab (Meaningful Play)	Hand exercise (squeezing)	Markerless AR	Google Glass	[61]
		HoloBalance	Virtual balance therapy	Exercise to improve balance & fall prevention	Markerless AR	HMD	[73]
		HOLOSTEP	Algorithm	Walking sessions	Markerless AR	HoloLens	[15]
	Multiple Sclerosis	MSease	Guidance	Visualize injection sites with the help of an overlaid AR grid	Marker-Based AR	Smartphone	[65]
	Parkinson's Disease	MTG (Moving Through Glass)	Dance intervention	Dance Activity/Exercise To improve mobility and balance	Markerless AR	Google Glass	[19]
Degenerative Disorders	Dementia/ Alzheimer's Disease	My Daily Routine (MDR) System	Guidance/assist	Receive personalized reminders/names of common objects and navigation instructions	Markerless AR	HoloLens	[60]
		cARe	Daily life support system	Step-by-step instruction/ navigation (caregivers will place key areas and details of the key areas will be displayed to the patient via HMD)	Markerless AR	HoloLens	[9]



FIGURE 15. Markerless augmented reality.

The table 5 also enlists the type of AR technology that has been used in the AR systems for tracking purpose. It has been figured out that most of the AR systems are using markerless technology as opposed to marker-based. Marker-based AR needs a prompt symbol or marker to initiate the augmented experience. To experience the marker-based AR, one requires a camera and some virtual objects to scan. In the real world when a marker is recognized by an AR application, the virtual 3D object, animation, or text is positioned on it to create the desired scene. The augmented 3D object will vanish if the scanner moves away from the marker. There could be many types of markers that can be used to scan such as QR code-like structures, images, cards, or other exceptional designs that an AR app can perceive, after identifying the trigger mark, it superimposes the virtual object on the top of it.

As compared to marker-based AR, marker-less AR is more adaptable as it lets the user decide where to put the virtual object. Without assigning a spot and putting a trigger over it, we can try various styles and different locations completely virtually, without moving anything in our environment. In this type of technology, even if your scanning device is moved around, the augmented object will stay in that spot. In figure 15 [58] shows the example of markerless AR, where a user is trying sit-to-stand exercise. The user can see a bird flying around his house. The game gathers a cherry as the user stands, and when he sits down, the game throws the cherry towards a specific target. In return, the bird rushes to grab the cherry.

In markerless AR, position/angle of the augmented object depends on the localization technology and gyroscopes but in marker-based, the placement of the object will be determined by the marker. So, the stability of the object in markerless AR is relatively higher than the stability in marker-based technology. But the position accuracy of marker-based is relatively higher than the position accuracy in markerless AR. So, it will depend on the requirement and usage of the system that which technology will work better.

B. GAPS AND CHALLENGES

While AR technology has made strides in integrating into the medical processes of treating neurological disorders, there are multiple challenges that arise with use of such an interactive and immersive technology. Some problems related to health and privacy concerns are already raised in previous

researches. This section presents challenges of using AR application in case of patient suffering from neurological disorder, who already has compromised cognitive ability. The challenges are listed below:

1) COGNITIVE OVERLOADING

With excessive use of 3D some patients with neurological disorders often do more spatial computing while using AR applications. This may create more cognitive load on the already stressed brain and nervous system. Research in [10] shows that AR HoloLens for Alzheimer's patients may often create a cognitive barrier for the user. Moreover, according to [6] a larger device size is needed for spatial representation, which may not always be available. This may cause the user to misperceive the space around them causing harm.

2) TECHNOLOGY LITERACY

Most applications of AR require hardware to run, which is a standard problem for the audience, which contains aged or impaired people. However, this is a huge challenge for people with neurological disorders. If an AR application requires some time for the user to learn and requires the user to remember it may be a problem as this target group has difficulty maintaining information. People with Alzheimer's disease/dementia cannot be educated over and over on how to execute said goal using AR. Research like [11] shows that often AR equipment needs a technician on hand and normal people without any disability need constant training on how to use applications.

3) MOVEMENT ERRORS

Applications of AR that rely on movement may have a higher error percentage due to omission errors caused by missed objects/vectors. This was experienced by LeapMotion in [17] where 5% of motions were incorrectly recognized due to fingers being omitted from the line of sight. This also was detailed by [7] where one size of AR hardware may cause an error for patients with different physical attributes.

C. UX (USER EXPERIENCE) GUIDELINES

Based on the challenges identified in the section above, a design requirement guidelines have been proposed as original work in this research. The goal of this design requirement is to overcome such challenges and provide designer/developer guidelines to make AR applications and systems that are more suited to people suffering from neurological disorders. Based on all three challenges identified, a design idea has been proposed to overcome that challenge as well hardware/software improvement that may lead to overcoming that challenge.

1) REDUCING COGNITIVE OVERLOADING

The most challenging thing about cognitive overload is that it requires a reduction in the system in terms of modeling, it also requires the system to have less text and less spatial input. This means that system needs to tune to lower quality,

which may impact the delivery of the system in terms of improvement. It is identified that often the application that targets patients with neurological disorders does not consider cognitive load as the main criteria. After considering each neurological disorder, a matrix has been provided where certain input and output should be avoided.

Based on the classification of neurological disorders described in [1] the input and output has been separated to be in either voice format, 2D model, or 3D model. This includes movement inputs, and gestures. Again, depending on the use case, the model may vary from case to case but generally, a designer should take into consideration each classification. Neurovascular diseases have been excluded as they are often treated with medication or surgical procedures (not via AR application).

The first classification is neuro-degenerative diseases, which include AD, Huntington’s Correa, PD, and CP are disorders where cognitive overloading is most expected. As degeneration is consistent and patients will keep losing memory over time it is not expected of them to remember actions and gestures of their own. Hence, input where movement can be avoided such as voice input is most preferred. Moreover, most of this order target brain, which may not require movement-related exercises hence, voice is the preferred input type. Voice input provides less cognitive overloading being nature input as well. In terms of output, this has been observed that lack of spatial intelligence is a big concern, which may also require a larger input/output device that may come with a physical load (such as a bigger headset) hence, voice-based outputs are better for output. The format can also be text-based 2D models as they are competitive and less difficult than complex 3D models. The 2D model also helps eliminate the need to analyze size, which people with neurodegenerative disorders have extreme difficulty with.

The second classification is movement disorders. These disorders are mostly contained in CNS and nerve disorders, which means that signals from the brain get disrupted. While most movement disorders are mostly degenerative if not treated but many disorders can be reversible with therapy.

This includes disorders like stroke or injury-related motor neuron disorder. Some cases of the degenerative disorder are also therapeutically maintained at the same level such as patients with CP with lower GMFCS levels are given a physical exercise to lower denegation level and keep muscle functionality.

Most AR applications for movement disorders are targeting that subjects doing hand and feet movement to replace traditional exercise-based therapy. It is imperative that such application target movement inputs hence, recommended input format is a gesture, physical inputting using a headset, gloves, or leg-based sensors.

Cognitive overloading is less of a problem for patients with movement disorder as analytical activity of the brain is not usually compromised. By training with input, the muscle and motor neuron functionality may be regained. Similarly,

TABLE 6. Input/output preferences of AR applications for neurological disorders.

Classification of Neurological disorder	Common Disorders	Preferred Input Type	Preferred Output Type
Neuro-Degenerative	Alzheimer’s, Huntington’s, Parkinson’s, CP (high GMFCS), etc.	Voice	Voice, Text, 2D model
Motor Disorder	Stroke, CP (lower GMFCS level), Motor diseases	Gesture, Movement Tracking	3D model, Interactive / Real life-size modelling

3D modeling in output is also preferred as patients have better spatial intelligence than Neuro-Degenerative patients. Moreover, the output may require future input as the next steps, which means that real-life-based 3D modeling with accurate sizes is a must for pin-point movement training.

Table 6 enlists the input and output preferences of AR applications for patients suffering from different neurological disorders according to the identified classification of neurological disorders.

2) TACKLING TECHNOLOGY LITERACY

The literacy problem was observed when AR applications have been tested with patients who suffer from long-term degenerative disorders. This was due to fact that a young person is less likely to develop a neurological disorder. Most patients are in a more advanced age bracket. This means that not only their memory may be compromised due to disorder but generally their ability to memorize, remember and navigate digital systems may already be very low.

This means the AR system treating such patients needs to be more in line with being elder-friendly technology, which most systems lacked. In this research, design rules have been provided as guides to designers along with the reasoning that can be incorporated to reduce the literacy gap for the AR system.

a: RULE 1: THE SYSTEM SHOULD BE EASY TO TURN ON WITH MINIMAL PHYSICAL INPUT

The system must be easy to start and should take less input from user to reach main state of application. This will also smooth user experience for patient to start application ever time and will counter difficulty patients face during starting the application such as remembering steps or navigating through screens.

b: RULE 2: THE SYSTEM SHOULD BE CONTINUOUS-SENSING FOR VOICE INPUT

The System should auto-sense for getting started and should be mostly audio based with the ability to accept multiple words/phrases for the same step.

The audio input allows the patient not to make complex movements to start the application /system and accept multiple input for the same action would allow patient not to remember exact input phrase each time such as next screen can have input words like “continue”, “next”, “forward” etc.

c: RULE 3: THE SYSTEM SHOULD BE AUTOSAVING THE SESSION

Most systems should sense user action and if the user decides to take a break the system should have the capacity to store and restore the same point.

d: RULE 4: THE SYSTEM HAS ASSISTANCE FOR PATIENTS

Patients may forget what is required next from them. Designers should include hints or guidance inform of text hints or maybe a virtual assistant in their application flow.

e: RULE 5: THE SYSTEM NEEDS TO BE LIGHTWEIGHT AND EASY TO SET UP

The patient may not be well versed in setting up the digital system and with AR applications that require a headset, display, and camera setup, wearable it may become more difficult. AR systems designed for neurological patients must be plug and play with less weight and cables.

3) REDUCING ERRORS

It is observed that errors while tracking movement significantly reduced the efficacy of the AR system. Patients with neurological disorders are already limited in movement and if they make a movement that may be quick, it might not get registered by the system. App designers need to keep error bars in applications to counter that, but it may vary from user to user. Some users may do movement a lot quicker than others which means preset error calculation may not be useful. Some state-of-the-art algorithms have been observed that focus on AR error correction, movement tracking, and input tracking. So, it is recommended that application designers implement such algorithms to lower movement errors.

a: SMOOTHING FRAME RATE

Applying to smoothing of captured frames in AR application with camera input: As the camera may take multiple frames for the same scenario, the key frame may lead to jitter. A special filter such as Kalman Filter may help to improve the jitter by smoothing to multiple frames [50]. Kalman also requires very less compute power. AI algorithms may also be applied to multiple frames, but they may be resource-intensive. However, CNN (Convolutional Neural Network), which runs locally or distributed DNN (Deep Neural Network i.e., TensorFlow) may be helpful to reduce the computer power requirement.

b: MULTIPLE TRACKING MODELS

Not every input would be 3D in AR applications. Some input may be 2D in nature which, means 3D tracking may lead to

some problems. It is observed some AR applications that use both a 2D fiducial tracker as well as two calibrated fiducials for 3D models such as in [2]. This can improve tracking and identification.

c: ENVIRONMENT FILTERING

Tracking movement may not require whole environment identification. In AR application sometimes due to background, certain motions are detected which are not the part of the use cases hence, it may lead to background noise being detected as false capture. In order to improve that, certain techniques such as image binarization can be used. Input with multiple frame can be divided into multiple layer using image binarization which can help remove extra noise and capture the movement accurately. Such correction layer can provide less movement error in AR applications targeting neurological disorders as the key idea is capturing movement.

d: SUPER-IMPOSITION

Frame capture can be super-imposed with another layer of different input capture such as thermal imaging. This would allow better error correction by combining different input types of the same frame.

Other algorithms such as the head-leveling algorithm and the optical tracking system may also be used to reduce the overall errors in movement.

A model on the basis of the presented design rules has been provided as shown in figure 16. This model is a guide for the developers to design a better and more user-friendly AR application for patients with neurological disorders.

By using chronological order in which normal applications are executed, presented model also runs in similar order with additional steps such as device setup and launching guidelines as well as correction and session saving layers. This allows the model to behave like a traditional AR system with improvements to facilitate the patients suffering from neurological disorders resulting in enhancing the patient experience significantly.

D. SUB-SYSTEM DIVISION FOR NEUROLOGY APPLICATIONS

A general model presenting the sub-system division for neurology applications has been proposed that provides meaningful play using AR technology for physical health rehabilitation of the patients as shown in figure 17.

It has been identified that the countries with growing percentage of population over 65 years of age have more proportion of patients suffering from neurological disorders [93]. This inherently causes the technology literacy issues, as learning to use AR applications could be difficult for the specified age group. The proposed sub-system enhances the user experience and reduces this technology literacy gap through automation.

It consists of the patient and therapist's subsystem. Each exercise that will be designed by the therapist for each registered patient will be rendered by this subsystem. The user

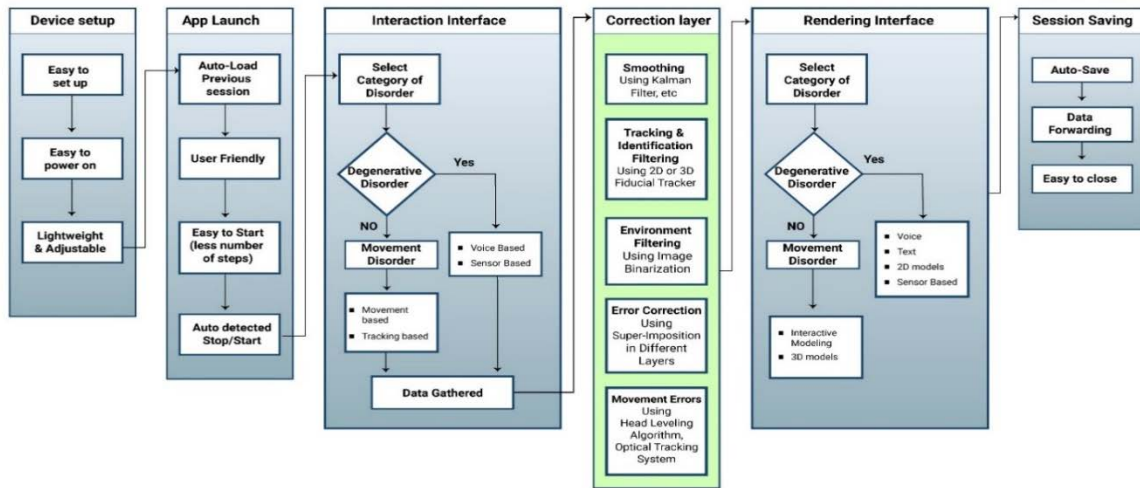


FIGURE 16. Proposed App structure based on design guideline.

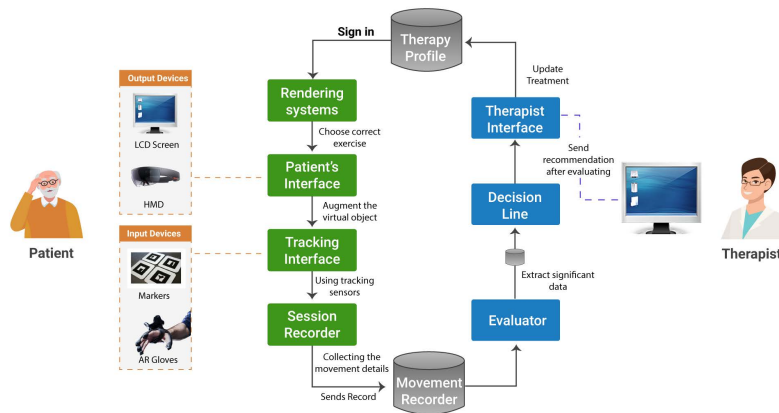


FIGURE 17. Sub-system division for neurology applications.

will log in to his profile to access the treatment plan from the patient-profile database. The recommended exercise can be rendered by the AR system. It can also keep a record of the number of exercises the patient has taken to assess the status of treatment. The rendering system could augment the virtual object into the real environment based on the exercise chosen using the marker. The patient will be able to experience it with a HMD. The tracking interfaces will be tracking the hand/arm movement of the patient with the help of AR gloves or MYO armbands. All the tracking will be stored in the patients' movement database by session recorder. This system also has a therapy adapter to update the database in case the therapist needs to change the exercise plan. This information will be passed to the adapter by the therapist's interface. On the therapist side, the session evaluator will have to figure out the significant performance record of the patient that will be evaluated by the decision support engine. The decision engine will check the performance and will pass the recommendation. The recommended results will be sent to

the therapist interface. Hence, the therapist can visualize and update the treatment plan if needed.

E. AR NEURO-APPS ARCHITECTURE BASED ON DESIGN GUIDELINES

To facilitate developers to make successful and result-yielding AR applications in the field of neurology, an architectural model has been proposed that is shown in figure 18 based on the gaps identified earlier. The input/output (I/O) processes in the architecture system of AR, presented in the previous studies, were general for all fields [101], [102] but in our model, we further categorized the interaction and rendering layers for different types of neurological disorders based on the reasoning defined in Table 6. Moreover, the model has start-up rules in the processing layer to minimize technology literacy and cognitive overloading. As this model is supposed to provide precise feedback to the therapist, so this model makes sure that the movement done by the patient is accurately tracked. For this purpose, we have added a correction

layer where we apply filters like kalman, smoothing, error correction, environment filtering etc.

Our model will serve as a guideline for the developers that are going to design an AR app for the diseases discussed in the paper. The design guidelines and solution has been incorporated into one robust, layered architecture that app developers can follow as a pattern for their application's implementation. The proposed layered architecture allows physical systems such as I/O different from the processing layer giving more liberty to the developer to pick and choose I/O accordingly. The general architecture of the data processing layer also takes into account the design guidelines we provide leading to better user experience, ease of setup, and keeping cognitive overloading to a minimum. It has also been described that how data would be gathered and maintained. This allows the model to translate more into the application layer where different types of systems can be attributed through the functioning of the preceding layers.

1) PHYSICAL LAYER

The physical layer contains the input and output devices as well as processing hardware for AR applications treating neurological disorders.

a: INTERACTION INTERFACE

In terms of Input, we have interaction interfaces. These are set of multiple input devices, which help to gather data from the subject and provide it to the central system. Interaction layers has been divided into further categories for different types of neurological disorders based on the reasoning defined in the previous section. Neurodegenerative disorders mostly have vocal, eye tracking, and emotion as input methods. This keeps the cognitive overload to a minimum while Movement disorders have mostly gesture and movement tracking as an input method.

b: RENDERING INTERFACE

Virtual content needs to be rendered to the end-user so that he can experience them as part of the real world. The division is also done in render interfaces, which is a major component of the physical layer responsible for the output. While degenerative disorders use audio, video, and 2D models the movement disorder mostly uses complex, interactive 3D models as output types.

c: TRACKING SENSORS

Physical layer also contains sensors for data gathering. The purpose of these sensors is to localize the AR system simultaneously to position and orientate the virtual object in the real environment. This includes AR-specific hardware such as movement trackers, eye trackers, computer vision hardware, etc. Mostly the AR systems like smartphones, tablets, or see-through glasses usually have at least one or more vision sensors including monochrome or RGB cameras. Specific systems also contain dedicated vision sensors like depth cameras.

d: PROCESSING UNIT

The physical layer also houses the dedicated processing unit such as CPU, GPU, and VPUs, which are the brains of the system. They contain the computation power for the AR system and processing for input and output.

2) DATA PROCESSING LAYER

This layer is the main layer for processing and provides step-by-step information of the actual flow of application. This layer uses the guideline on how all AR applications targeting neurological need to define their flow.

The first step is to start the hardware. This includes the guidelines that have been described in the previous section. The hardware is easy to setup and it should be lightweight. Once the hardware setup is done and the application is launched, the application needs to interact with the session dataset to restore the previous successful state. Then, the application must transfer into a data-gathering state, which will use interaction interfaces from the physical layer to gather data from the user. All the localization, scene analysis and mapping is handled by vision engine. Vision engine is the computer vision code that detects and interprets frames capture by AR devices. It is part of all AR devices as main component that helps detect objects and interpret environment.

Enormous input and output data need to be stored and maintained, as the system needs to store processing data as well as the state of the system. Hence, the section of data collection has been introduced under the abstraction set. Although this has not been described, which specific hardware can be used as AR systems vary from head-mounted displays to mobile devices? What this section describes is a different type of data sets. The data/frames captured by the AR system for environment mapping are stored in the world knowledge dataset including data on the plane, lights, and occlusion. For an AR system to render different output there also needs to contain data storage that houses interactive content data. This includes variables that would be required to output processing data including content, superimposition data, and different layer fusion data.

While another dataset may be part of any generic AR system, what we have introduced in the data collection layer is the session management dataset. This dataset is critical to any application that treats neurological disorders as it maintains the application's state for the user so when the user relaunches the application the previous successful state is automatically restored keeping the application complexity and specifically start-up complexity very low. This also reiterates the design guidelines that application support auto-start and restore the last checkpoint to reduce huddle for technology illiterates.

3) APPLICATION LAYER

These include sub-systems that is interacting with users directly. This may include systems that take data from the

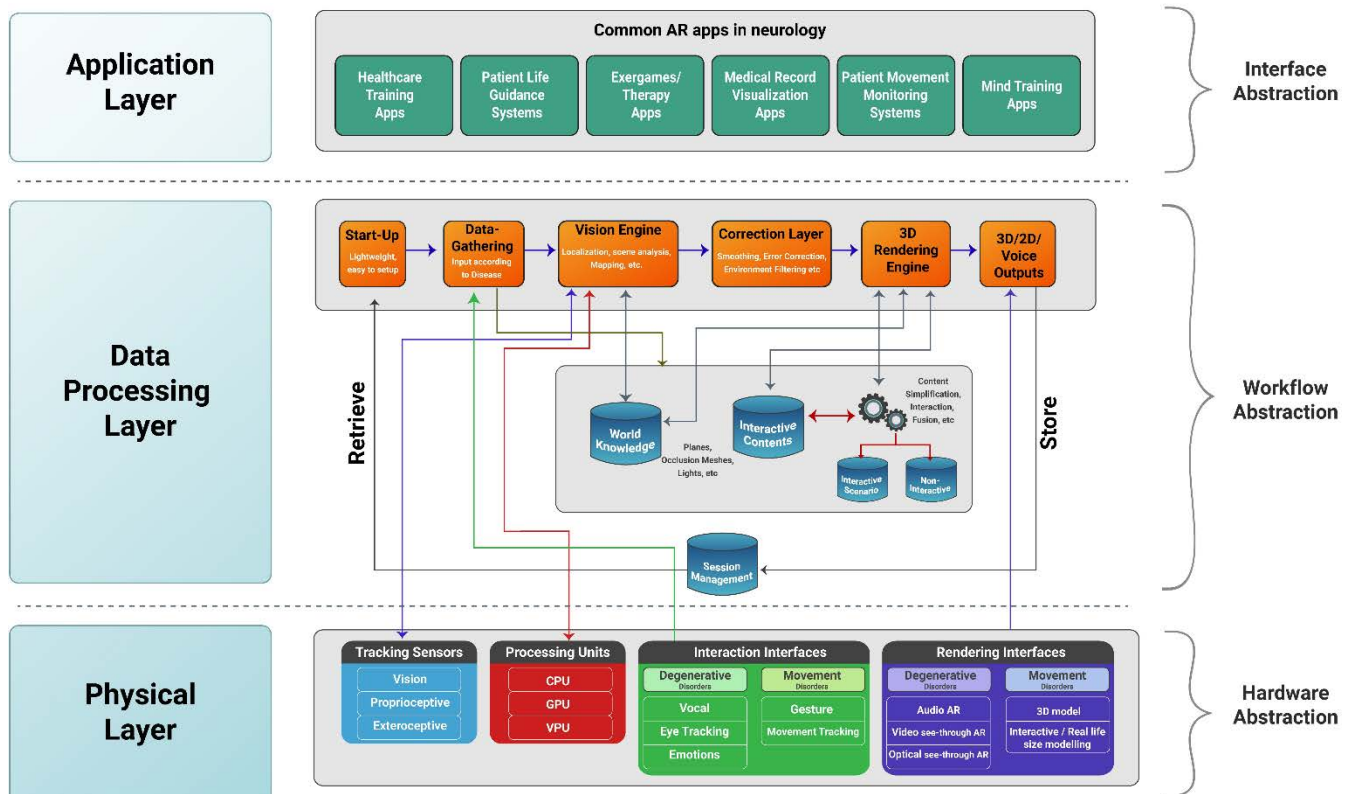


FIGURE 18. Proposed AR neuro-apps architectural model based on design guidelines.

user or output it to him as well as systems that provide data to therapists or medical care providers. For the application, it has been divided into two categories: patient-side application and healthcare worker-side application.

a: PATIENT-SIDE APPLICATION

This subset represents applications in which the patient directly interacts in terms of input and output interactions and the main actor in the application is the patient. This includes an application that provides therapy information of exergames or they may application, which provide patient assistance such as daily task assistance application, social application. Some applications are also present which provide mental training exercises. Most applications are running on small hand-held devices such as smartphones and tablets. Some applications may also be on HMD.

b: HEALTHCARE WORKER-SIDE APPLICATION

These applications are supplementary applications, which predominantly used by healthcare workers such as doctors, surgeons, nurses, and personal healthcare staff. There are further two types of applications. Some applications provide assistance and training to healthcare workers without any patient involvement. This application provides training such as surgery training or emulates medical records in AR format such as medical record visualizers, which help doctors do diagnoses and treatment more accurately. Other applications are data collection applications that gather data from the

patient-side application and provide it to the therapist to analyze the patient progress. They may be tracking application that gathers movement data or monitoring application that helps track patients’ vitals.

V. CONCLUSION

This paper presents a systematic literature review that comprehensively investigates the applications of AR techniques in neurology. A total of 47 papers were finalized from a subset of 135 papers that met a criterion to shortlist the relevant articles. This SLR identifies AR applications, the types of disorders being treated in the field of neurology through AR applications, and types of improvements along with limitations these AR applications pose. A point-based evaluation was done for all the collected papers.

A taxonomy depicting different aspects of AR applications in neurology has also been presented. The identified limitations in studies are highlighted, which are found while using AR for the treatment of neurological disorders. The technology literacy, cognitive overloading, and movement errors are identified as some of the challenges of using the existing AR systems. To address these challenges, a model exhibiting a potentially robust AR system has been proposed. It is based on the type of disease, preferred interaction mechanism, and different computation techniques to improve results. The model emphasizes the specific input and output types as per the understandability of the patients and the different types of disorders. The general architecture has also been suggested

to build the AR systems. This research provides a guideline for future work in terms of using AR in neuroscience and suggests application developers an approach to develop a capable AR system for patients with neurological disorders. The model needs to be tested aggressively in real world settings to identify more challenges faced by patients.

As per our findings, physical rehabilitation using AR is the most common type of system found in neurology. This also is coupled with the fact that more AR systems are used for motor disorders while only a very few systems are designed for patients with degenerative diseases, most of them being task assistance systems.

Motor disorders can also be treated using regular therapy or physical rehabilitation programs. Hence, there is a need of using interactive technology such as AR systems to provide diagnostic or treatment rehab processes to patients with degenerative diseases and explore the possibility of using AR systems for mental rehabilitation. The AR applications mostly leave long-term impact on patient's journey through which the patients' capability to respond to the day-to-day activities and events are improved.

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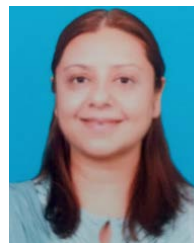
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