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SMART HOMES FOR DISABLED PEOPLE: A REVIEW STUDY

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ABSTRACT:

The field of smart homes has gained notable attention from both academia and industry. The majority of the work has been directed at regular users, and less attention has been placed on users with special needs, particularly those with mobility problems or quadriplegia. Brain computer interface has started the mission of helping people with special needs in smart homes by developing an environment that allows them to make more independent decisions. This study investigates the efforts made in the literature for smart homes that have been established to manage and control home components by disabled people and makes a comparison between the reviewed papers, in terms of the controlled devices, the central controller, the people with disabilities the system is meant for, whether or not machine learning was used in the system, and the system's command method. In the field of machine learning-based smart homes for disabled people, the limitations have been pointed out and talked about. Current challenges and possible future directions for further progress have also been given.

KEYWORDS: Smart Home, Disabled People, EEG, Machine Learning, IoT, Brain Computer Interface.

1. INTRODUCTION

Technology is making people's lives easier than ever before, but not for everyone, particularly Persons with Disability (PwD). A disability is defined as any medical condition that makes it difficult for a person to do specific activities or interact effectively with the world around them. Recent EEG devices with non-invasive, wearable, low-cost, wireless, lightweight, and easy-to-use features have piqued the interest of academics from a wide range of disciplines, particularly in Smart Homes used as command methods (Elshenaway & Guirguis, 2021). Traditional smart home solutions work by receiving voice commands or via smart devices such as touch screens, but not much attention has been paid to physically disabled people.

According to the World Health Organization (WHO), over one million people are disabled by early 2022[1]. Smart Home is a home technology that allows housework or household activities to be automated (Gram-Hanssen & Darby, 2018; Jacobsson et al., 2016), as it produces services and information from a composite of other data with little or no human intervention (Yang et al., 2017). Thus, it is a conventional home with some home automation technologies that essentially extract data about the environment and consistently support home services (Xu et al., 2018). Sensors in smart homes collect data from their surroundings, and this user and factor-based data can potentially be used to construct intelligent models that will make smart homes even smarter in terms of usability and power consumption (Elmisery et al., 2019). On the other hand, the Internet of Things (IoT) is a system of interconnected devices that interact with one another, and gather a massive quantity of data daily (Zantalis et al., 2019).

This review paper examines efforts to improve the ease of use and comfort of people with disabilities living in their smart homes. In this regard, the brain-computer interface (BCI) systems have been developed that attempt to enable the disabled people to control home appliances, by allowing direct interaction between the human brain and electronic devices without the requirement of additional physical parts. In this context, the brain-computer interface allows a person to control any electronic device simply with their brain neuro-commands. As for many people who are extremely immobilized, it is their only means of communication (Bahri et al., 2014).

The rest of this paper is organized as follows: Section II provides a brief overview of PwD. Section III discusses the fundamental principles of smart homes. Section IV introduces the key concepts and technology behind the Brain Computer Interface (BCI). Section V provides an overview and summary of the available smart home systems for PwD in the literature. Section VI discusses the findings of the current review. Finally, Section VII concludes with outstanding questions and potential future directions.

2. PEOPLE WITH DISABILITY

A person with a disability is a state of dysfunction in which a person is subjected to environmental harm, activity limitations, or disability caused by a disease, ailment, accident, or other health concern. Understanding the health and environmental components of disability allows researchers to investigate environmental change treatments to increase the positive engagement of people with disabilities, as well as health therapies to enhance functioning (Leonardi et al., 2006). Traumatic brain injury and stroke are examples of brain dysfunction. Another type of disability is caused by spinal cord and spinal cord dysfunction, such as spina bifida, which is common (Retief & Letšosa, 2018). For a better usage experience, smart homes for physically disabled people must provide both hand-free control and adaptively features. Most importantly, it should assess the mental condition of people with disabilities, considering their ability to make the right decisions in order to avoid putting themselves in danger.

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3. SMART HOME

The Internet of Things (IoT) is a network of internet-connected items that can collect, send and receive data about their own status as well as their surroundings (Xu et al., 2018). Thus, IoT is the link of items, such as home and vehicle apparatuses that contain hardware, systems, actuators, sensors, and networks that permit these devices to associate, communicate, and send or receive data among each other. When embedded with technology, these devices can exchange and connect through the network, allowing them to be remotely monitored and controlled.

The ability to perceive updates in the actual status of devices is also crucial for understanding historical changes on the planet. Sensors in an electronic coat can detect changes in our temperature, and the boundaries of the coat can be changed in the same way (Elmisery et al., 2019). A smart home, on the other hand, is a setting with many front elements and heterogeneous systems that are supported by embedded information and communication architectures (Babakura et al., 2014).

It is also being defined as a system in which digital sensing and communication technologies are integrated to provide services through seamless communication (Gram-Hanssen & Darby, 2018) to automate housework or household activities (Jacobsson et al., 2016) by producing services and information from a composite of other data with little or no human intervention (Yang et al., 2017). Shortly, smart homes are ordinary houses outfitted with home automation systems that collect information about the environment and help with home services (Balakrishnan et al., 2018).

4. BRAIN COMPUTER INTERFACE

A BCI is a connection between the brain and technology that allows the brain to control external movements, such as cursor movement or prosthetic limb control, as shown in Fig. 1. By receiving, pre-processing and classifying brain wave signals from an array of neurons and converting them into activity using computer chips and programming, a BCI system can allow a person with immobility to manage a smart house, motorized wheelchair, prosthetic limb or technically any controllable electronic device or system (Lukoyanov et al., 2018).

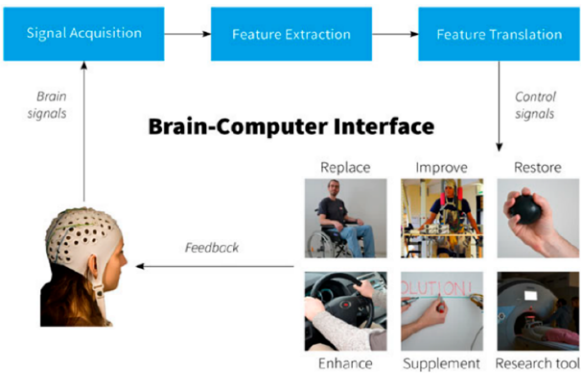

FIGURE 1: Principle of a brain-computer interface including possible application scenarios (Brunner et al., 2015).

The brain is made of approximately 100 billion nerve cells, with a distributed electrical brain activity that can be observed non-invasively using the low-cost and mobile technology of electroencephalography (EEG) (Graimann et al., 2013) . The EEG is a technique for measuring electrical activity in the brain in order to track or interpret neuro-electrical patterns. It is often used to show the presence or absence of the brain's reaction to both physical and non-physical stimulation and for BCI applications, including brain/mind controlled smart homes. The commonly used EEG technologies for BCI applications are as follows:

4.1 Emotive Insight Headset

The smallest and less expensive EEG headset from Emotive with 5 electrodes, (as shown in Fig. 2). The larger and more costly types include the Emotive Epoc with 14 electrodes and EPOC FLEX with up to 32 electrodes (de Lissa et al., 2015). Users of BCI systems can practice mental commands by playing games such as Arena (LaRocco et al., 2020).

FIGURE 2: Emotiv Insight EEG Headset *("INSIGHT - 5 Channel EEG Brainwear®," n.d.)*.

4.2 InterAxon Muse Headset

The InteraXon Muse, shown in Fig. 3, is a small EEG headset that analyzes brain activity using four EEG sensors and sends data to surrounding devices via Bluetooth. According to Muse, the headband can help the wearer attain a profound state of relaxation. Dry electrodes are placed at FPz, AF7, AF8, TP9, and TP10 according to the 10–20 international electrode placement protocol (Krigolson et al., 2017).

FIGURE 3: InterAxon Muse EEG Headset (Muse™ - Meditation Made Easy, *n.d.)*.

4.3 Neurosky Mindwave Headset

As shown in Fig. 4, Neurosky's Mind Wave is a low-cost, single-channel, dry EEG headset that can exchange data wirelessly using Bluetooth low energy or standard one. The electrodes are put on the ear, while the EEG electrode is located above the eye on the forehead. The Neurosky EEG headgear comes with training software, educational programs, and a software development kit (Nugroho & Fahruzi, 2019).

FIGURE 4: Neurosky Mindwave EEG Headset (MindWave, *n.d.)*.

4.4 Open BCI Headset

The Open BCI Ultracortex Mark IV is a 3D-printable, open-source headset. It can record EEG data of high quality for research purposes. Based on the 10–20 International Systems, the headset can sample up to 16 channels of EEG from up to 35 distinct places. It was previously utilized in a driving simulator to detect tiredness (Mohamed et al., 2018). Fig. 5 shows the Open BCI Ultracortex Mark IV.

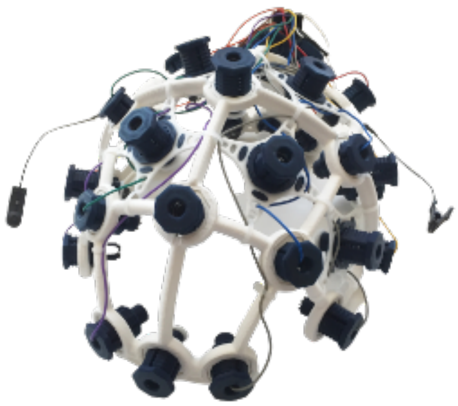

FIGURE 5 : Open BCI Ultracortex Mark IV *(*Ultracortex Mark IV | OpenBCI Documentation*, n.d.)*.

5. STUDIED LITERATURE

This section presents different smart home systems that are intended for the disabled and those with limited mobility, with the possible support of machine learning models.

5.1 Systems Supporting Ml

Sri and Naren (Sri & Naren, n.d.) proposed a system for developing an IoT-based mobile gateway solution for interactive home wireless systems, monitoring and control, and data collection systems that would send SMS and email warning to mobile phones. Machine Learning is being employed to enable the IoT system to analyze and evaluate sensor data, seek for correlations, and determine the best response to be taken. Moreover, data on a patient's heart rate, ECG, and body temperature are recorded and sent to a decision-making system, which employs fuzzy rules to determine how frequently patient data is classified as normal and critical.
Hussein et al. (Hussein et al., 2014) attempted to analyze many aspects of the smart home, including home automation, comfort, safety, and health. Their proposed method is based on using two types of neural networks to learn about people's habits and activities in order to predict their next move. The interface devices provide easy access and control of the permanent system. However, the system is not ideal for people who are unable to move since it is not intended to read brain signals.

5.2 Systems Without ML Classified by Command Type

The majority of the research reviewed did not incorporate ML methods, and several studies made use of brain signals to control them. Most of the current systems are based on using smartphones to send commands to a smart home in order to control home appliances, while others used eye-tracking and a flex sensor to receive commands from the user. Work that requires the use of an EEG headset is preferred for PwD, because it does not require a specific movement from the user, making it easier and more convenient. The following are the reviewed researches based on the command method used:

5.2.1 EEG Headset: Zhang et al. (Zhang et al., 2020) proposed that an electromyogram (EMG) signal associated with the occlusal movement merged with steady-state visual evoked potentials (SSVEPs) in order to develop a hybrid brain-computer interface (hBCI)-based smart home management system for patients with paralysis. In order to detect SSVEP patterns as intentional selection, researchers employed a technique called classical correlation analysis (CCA) on four-channel EEG data. Several distinct occlusal EMG patterns were taken from the single channel of the temporalis muscle and utilized to verify the function that was being used, to return from the sub interface to the main interface, and to turn the system on and off, respectively. The system control module was compatible with a variety of devices, which enabled wireless communication with a variety of equipment, including beds, wheelchairs, TVs, telephones, curtains, and lamps, through the use of ZigBee networking. The SSVEP paradigm was used in the development of a system that has one main interface, five sub-interfaces that correspond to multiple devices while the system is in the working state, and one interface when the system is in the idle state.
Rajmohan et al. (Rajmohan et al., 2020) intend to provide a significant mode of interaction between BCI and processors in order to make it much easier to handle any household appliances in daily life. A Neurosky headset is used because the brain impulses are recorded by a sensor placed over the head. The sensor module performs the fundamental pre-processing and data refining, which is then delivered to the intermediate interface, which is the Android smartphone. The smartphone application receives the signal and attempts to decode it according to the established rules. If the brain reading matches the expected reaction, it also creates the control signal. Many features are included in this project, such as a unique coding technique for managing a larger number of devices and providing security against unauthorized control. It makes use of an Arduino microcontroller to set the threshold for toggling the gadget depending on brain wave reader readings. A Bluetooth module is used to create communication contacts.
Qin et al. (Qin et al., 2020) developed a wireless EEG-based BCI smart home control system for disabled people that is portable, cost-effective, and real-time. A prototype device is being created utilizing a Raspberry Pi 3 Model B+, a 4 channel 5V relay module, a light bulb, and a fan. The raw data signal from the brain wave is recovered and used to operate household appliances.
Jafri et al. (Jafri et al., 2019) proposed a smart home system for the elderly and those with disabilities. The main purpose was to develop and test a system that would allow paralyzed, disabled, or elderly people to do basic daily tasks such as controlling household appliances and monitoring vital signs without the need for assistance.
The NeuroSky MindWave EEG sensor, as well as android software that allows the user to control four different household appliances, was presented by Nafea et al. (Nafea et al., 2018). To operate the appliances, the android app is connected to an Arduino Uno board through an HC-05 Bluetooth module in order to control the appliances. A Bluetooth connection between the EEG sensor, the Android app, and the Arduino board results in a portable smart home system with low power consumption.
Alrajhi et al. (Alrajhi et al., 2017) proposed a smart home system based on BCI that enables a paraplegic to open and close doors using just their brain impulses, eliminating the need for a caregiver. Emotive Epoc+ was used to detect the user's brain signals. The Two Emotive suites, Cognitive Suite and the Facial Expressive Suite, were also utilized and assessed to demonstrate the technology's capabilities for people with disabilities. In order to detect which suite is best for everyday use, the results of the two suites were compared in terms of training time, signal generation simplicity, detection effectiveness, and user preference, among other things.

The study of Lee et al. (Lee et al., 2013) aims to use a non-invasive brain-computer interface to control household gadgets (BCI). The Emotive EPOC headset collects electroencephalographic (EEG) data from brain activity, which is then interfaced to a graphical user interface (GUI) on the computer screen through mouse emulation. This user interface is used to operate a variety of smart home devices.

Masood et al. (Masood et al., 2016) proposed an approach to assist handicapped and needy people. Electroencephalogram (EEG) data from brain activity is detected using the Neurosky headset. They were able to correlate brain activity for certain concepts and eye blinking patterns with the switching and regulating of various household appliances by recognizing brain activity for specific ideas and eye blinking patterns. The accuracy of BCI-based devices ranges from 80 to 100 percent.

The goal of Zaki et al. (Zaki et al., 2018) work was to show that a neural pattern recognition interface acquired by Emotiv EPOC could be used to control a home device. The pattern is sent to a client, which sends it to the server, where a Raspberry Pi microcontroller receives it. Based on the information received from the client, which switches on or off the television, the microcontroller delivers the necessary response. This software has enormous promise, particularly for patients suffering from Amyotrophic Lateral Sclerosis (ALS).

Contreras-Castañeda (Contreras-Castañeda et al., 2019) proposed a ground-breaking multimodal interaction system that allows people with restricted physical mobility to oversee and control a home automation system through three separate types of human touch. The first is based on Neurosky non-invasive wearable and a BCI and EEG on surface electroencephalographic electrodes. In this situation, the BCI is controlled by human blinking. The second employs spoken commands and voice recognition technology, while the third is based on a programmable touch screen of a mobile device. All three-interaction modalities can be swapped out depending on the user's demands.

Poveda Zavala et al. (Poveda Zavala et al., 2018) proposed and developed a brain-computer interface for patients with movement difficulties. Their proposed system can read, monitor, and translate brain waves generated by a person with movement difficulties in order to replace or rehabilitate natural movements or to control various devices such as domestic appliances. In this work, the prototype of the suggested solution uses a control mechanism based on raw EEG data collected by the MUSE headband to manipulate real-world domestic appliances coupled to an Arduino system.

Gao et al. (Gao et al., 2018) presented work on an online BCI-based smart home system that can detect multi-commands and control smart devices using steady-state visual evoked potentials. The portable EEG acquisition device of Emotive EPOC was used to collect EEG data. To supply electrical energy and communication for those devices, the Power over Ethernet (PoE) technology was used. Four different control commands were achieved during online testing to operate four smart home devices (lamp, web camera, guardianship telephone, and intelligent blinds).

Samson et al. (Samson et al., 2018) used an inexpensive device called Open BCI Ganglion to control home appliances or any other form of electrical device for physically disabled people. Using Open BCI Ganglion and "gold cup electrodes" (GCE), the EEG signals are captured from the client's cerebrum activity. The Arduino Uno, which is used to control electronic equipment, was utilized to manage the EEG signals that are produced at various degrees of repetition, as well as eye movement and concentration.

5.2.2 Smart Phone: Bajpai and Radha (Bajpai & Radha, 2019) investigated the possibility of operating all the devices using a single remote control rather than one for each instrument. With Bluetooth connectivity between any current smartphone and an Arduino microcontroller, this global controller can be simply created at a low cost. As a result, control devices based on smartphones reduce the need to carry a variety of remote controls. Furthermore, using speech to control devices eliminates the need to search for multiple buttons/options when using the equipment.

Rashid et al. (Rashid et al., 2017) developed a smart home automation system with automatic light control that turns on when a human is present and turns off the rest of the time, Bluetooth remote controlling capability, automatic water tank fill-up, automatic water tap, automatic door lock and open system, and a solar charging system with a solar controller to reduce power consumption. The Arduino-based project was built using low-cost components to create a system that can reduce water waste in real time while simultaneously lowering electricity and utility costs by using renewable energy as a source of power.

Ramlee et al. (Ramlee et al., 2012) attempted to build a smart home system that included a Bluetooth-based wireless controller. This software application is compatible with Android-based mobile phones, PDAs, and mobile computers (Samsung Galaxy Tab) (OS). The electrical appliance switches are controlled remotely by this software application (Bluetooth). The system can be utilized in hospitals, nursing homes for the elderly, and institutions for PwD.

As explained earlier, the works of (Sri & Naren, n.d.) and (Hussein et al., 2014) are also controlled by smartphones, in addition to being supportive of ML techniques.

5.2.3 Eye and Flex Sensors: Bissoli et al. (Bissoli et al., 2019) proposed an eye-tracking-based assistive system for controlling and monitoring a smart home powered by the IoT, which was designed using user-centered design and usability principles. Using this technology, a person with a significant impairment may control important domestic devices such as lights, television, fans, and radios. Some users' eye movements in this system are often unintended. This causes the system to react in an unusual way, making it hard to keep the user's eye position.

Kshirsagar et al. (Kshirsagar et al., 2020) presented a glove-based home automation system that identifies gestures and hence allows automatic device control. Simple movements may operate household gadgets while wearing the glove, which has band and flex sensors with an Arduino microprocessor and Bluetooth module. As a result, the system delivers comfort to PwD while also notifying caregivers.

Table 1 presents a systematic comparison of the various systems designated for PwD in terms of the technology used and the method of handling the user, as well as the system's strengths and limitations. Fig. 6 also displays weather the system employs ML or not, as well as command methods.

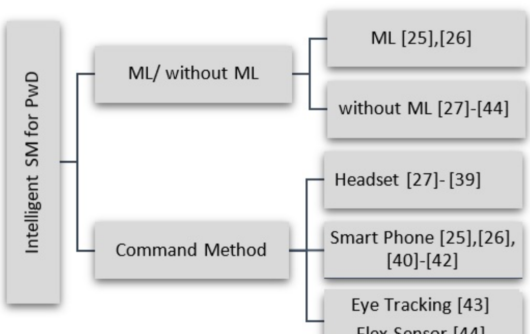

FIGURE 6: Taxonomy of the literature review

Table 1. comparison of a smart home for disabled people

Ref	Command Method	ML Algorithm	User Interface	Type of user disability	Central controller	Devices and Sensors	Strength	Limitation	Communi-cation technology
(Sri & Naren, n.d.)	Smart Phone	fuzzy logic	No	Disabled and Sickness	Raspberry Pi	light, door, windows fan, Heartbeat rate, body temperature, ECG report, fall detection.	ML-based analysis	Unsuitable for limb movement difficulty	Wireless
(Hussein et al., 2014)	Tablet, Microphone	Neural Network	Yes (Visual Studio C#)	Disabled People	PC and Arduino	Lights, TV, AC, Coffee Machine, Music	Use of ML for adaptive smart home	Not adapted for mobility disabled people	Wireless
(Zhang et al., 2020)	EEG Headset (P300)	No ML	Yes (SSVEP/MATLAB)	People with paralysis	PC	beds, curtains, TVs, lamps wheelchairs and telephones	capability of the SSVEP paradigm for selecting many targets at once	A 64-channel EEG cap was used, which is a cumbersome piece of equipment that is both expensive and uncomfortable to wear.	Wireless
(Rajmohan et al., 2020)	EEG Headset (NeuroSky)	No ML	Yes (android)	Physically Disabled	Arduino	Light, Fan, TV	No need to stand in front of a screen to operate devices; ease of using the phone	No storing of data. No support for ML	Bluetooth
(Qin et al., 2020)	EEG Headset (NeuroSky)	No ML	Yes (MATLAB)	mobility problem	Raspberry Pi	Light bulb, CCTV camera, fan	Use of MindWave Headset	Not supporting ML	Wireless
(Jafri et al., 2019)	EEG Headset	No ML	Yes (android)	Totally physically Immobilized	Arduino	fan, blood pressure Bulbs, and IR therapeutic belt.	Support for Total Immobility	not support any ML intelligence	Wireless
(Nafea et al., 2018)	EEG Headset (NeuroSky)	No ML	Yes (android)	Disabled and Elderly	Smartphone + Arduino	PC, a monitor, a Wi-Fi router, and a kettle	Helping handicapped individuals.	Not collecting data. Not supporting ML	Bluetooth
(Alrajhi et al., 2017)	EEG Headset (Emotiv, Epoc+)	No ML	Yes (MATLAB)	Quadriplegia	PC and Arduino	Open/close doors	Cognitive Suite and the Facial	Not collecting data. Not supporting ML	Wireless

							Expressive Suite.		
(Lee et al., 2013)	EEG Headset (Emotiv, EPOC)	No ML	Yes (Emotiv software)	Special Needs	PC + 8051	TV, MP3, temperature control, lights, doors	Using EEG headset to control home appliance	Not supporting ML	Wireless
(Masood et al., 2016)	EEG Headset (NeuroSky)	No ML	Yes (PC application)	Handicapped and Needy	Arduino	Fan, bulb	No physical action is needed of the user.	Not supporting ML.	Wireless
(Zaki et al., 2018)	EMOTIV EPOC+	No ML	Yes (Emotiv software)	Amyotrophic Lateral Sclerosis (ALS)	PC and Raspberry Pi	TV	Help people with Amyotrophic Lateral Sclerosis (ALS)	No collecting of data. Not supporting ML.	Bluetooth
(Contreras - Castañeda et al., 2019)	NeuroSky MindWave	No ML	Yes (android)	Physical Mobility	Smartphone and Arduino	auxiliary lamp, Main lamp, radiator and HiFi sound	Three modes of human engagement by multimodal interaction system.	No storing of data. No support for ML	Wireless
(Poveda Zavala et al., 2018)	EEG Headset (MUSE headband)	No ML	No	movement disabilities	Arduino	Fan, bulb	using blinks since most people with movement disabilities (even the most serious) can do this kind of movement.	not support any ML intelligence	Wireless
(Gao et al., 2018)	EEG Headset (Emotiv, EPOC)	No ML	Yes (SSVEP/MATLAB)	paralyzed and elderly people.	PC	lamp, web camera, guardianship telephone and intelligent blinds	new way for supporting life of paralyzed people and elderly people	Not collecting data. Not supporting ML.	Wireless
(Samson et al., 2018)	EEG Headset (OpenBCI Ganglion)	No ML	No	incapacitated individuals	PC and Arduino	electronic gadgets	multiple electrodes are used but	The information is not saved, and	Wireless

							four electrodes are considered	machine learning isn't employed	
(Bajpai & Radha, 2019)	smart Phone	No ML	No	Disabled and Elderly	Arduino	Light, Fan, Switch	Voice based controlling	No support for speech problems	Bluetooth
(Rashid et al., 2017)	Smartphone	No ML	Yes (android)	Physically Disabled	Arduino	Automatic control for light, fan and water pump, motion detector, IR, ultrasonic	Renewable energy Decrease water waste in real-time.	Not adapted for mobility disabled people	Bluetooth
(Ramlee et al., 2012)	PC, Smartphone	No ML	Yes (android)	Handicapped	PIC	Humidity, temperature sensors, IP camera	Remote monitor and operate electrical appliances.	Not adapted for mobility disabled people	Wired and Wireless
(Bissoli et al., 2019)	Eye-Tracking	No ML	Yes (Eye tracking PC software)	Inability Reduced mobility	PC	Lamps, television, fan, and radio	Multi-user mode	Hard to maintain a consistent eye position	Wireless
(Kshirsagar et al., 2020)	Flex Sensor as gloves	No ML	Yes (android)	Disabled and Elderly	Arduino and Raspberry Pi	Bulbs and fan	Glove for a patient	Not supporting ML.	Glove Wired, Bluetooth

6. DISCUSSION

This work investigated smart home technologies for people with disabilities to let them control their household appliances and make their smart homes more comfortable in terms of usability. The literature was reviewed for a variety of systems for PwD. The researched literature is divided into two main groups in terms of design and performance; also, in terms of supporting ML principles and controlling command mechanisms, they are as follows:

1. Systems supporting ML concepts: As a matter of fact, not all smart homes designed for disabled people use intelligence from machine learning techniques and algorithms. As shown in Fig. 7, the works of (Sri & Naren, n.d.) and (Hussein et al., 2014) are the only systems that have integrated ML algorithms into smart homes and demonstrated the ability to add new functionalities to smart homes for people with disabilities as: (a) to be interactive with the user and (b) to classify the state of the environment and determine the appropriate action to take for the user. The work of (Sri & Naren, n.d.) outperforms (Hussein et al., 2014) in terms of monitoring user health status. In addition, both systems have difficulties being used by PwDs who have mobility limitations.

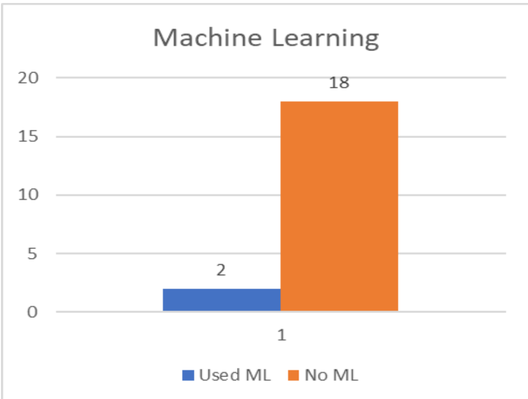

FIGURE 6: Systems that use ML and those that do not use it.

2. Systems not supporting ML concepts: In other studied systems, ML is not integrated with smart home systems for PwD, hence they are not adaptable to the user behavior. Figure 8 shows the number of systems that use EEG, smartphones, and eye tracking and flex sensors as command methods for the system.

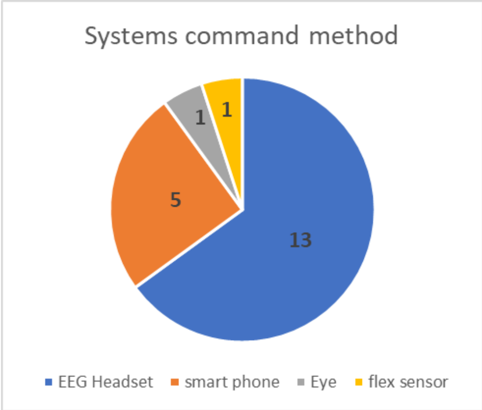

FIGURE 7: System command method types

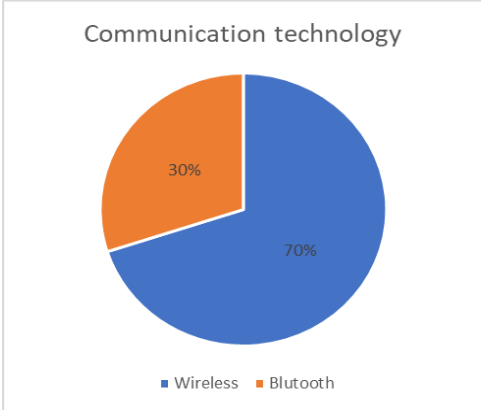

FIGURE 8: Communication technology that is used in systems

These systems are categorized according to the command methom, as follows:
EEG Headset: Thirteen of the studied works (Alrajhi et al., 2017; Contreras-Castañeda et al., 2019; Gao et al., 2018; Jafri et al., 2019; Lee et al., 2013; Masood et al., 2016; Nafea et al., 2018; Poveda Zavala et al., 2018; Qin et al., 2020; Rajmohan et al., 2020; Samson et al., 2018; Zaki et al., 2018; Zhang et al., 2020) have used headsets as a controlling command method. These systems mainly use brain waves to select user choices, making them more suitable for PwD who have mobility or speech problems. Some systems, such as (Zhang et al., 2020), use headsets with screens in fixed places to operate home appliances, and to use the system the user must stand in front of the screen at every use of the system, which makes it uncomfortable for people with disabilities due to the difficulty of moving them at every use. The works in (Qin et al., 2020) and (Zaki et al., 2018) outperform others by using RPi instead of Arduino, as being a more powerful and faster processor with the support of multitasking capabilities. The main limitation of these works is that no data has been collected to be utilized for further support of ML models.
Smart Phone: This command method is difficult to be used by PwD who have problems with speech and physical disabilities. Besides that, these systems do not collect data and do not have ML support. The smart home systems of (Bajpai & Radha, 2019; Ramlee et al., 2012; Rashid et al., 2017) used smartphones to interact with users and based on voice recognition instead. The work of (Rashid et al., 2017) outperforms the others in terms of renewable energy and decreases water waste in the home in real-time.
Eye Tracking and Flex Sensor: The controlling command method for the two smart home systems presented in (Bissoli et al., 2019) and (Kshirsagar et al., 2020) are eye-tracking and flex sensors. The work of (Bissoli et al., 2019) outperforms (Kshirsagar et al., 2020) in terms of having a friendly UI and multi-user mode. However, both works do not collect data and lack the support of ML techniques, therefore not being adaptive.
Most of the systems that have been created for people with disabilities use Bluetooth and wireless technology, as shown in Figure 9, to eliminate the need to extend wires between the user and the central controller and to be used by the disabled in an easy and more flexible manner.

7. CONCLUSION

With the rapid emergence of futuristic technologies, including smart homes, physically disabled people are the most marginalized members of the society in terms of receiving benefits from the available high-tech solutions. Smart homes used to provide a comfortable and easy environment to turn on and off home appliances for their users, but the PwD are still the people who need the most help controlling their smart homes with both appropriate user-friendly and comfortable solutions. This work presented the current state of the art of smart home technologies that are made for physically disabled people. The notable research gap in this area is the continued lack of compound systems that support both ML ideas and primary expected usability aspects for mobility-disabled individuals, such as taking into account both user behavior and environmental elements such as weather conditions.
By reviewing papers, we find that there is a lack of use of ML and no collection of data, which makes them not intelligent and not adapted to the user except for the papers [26] and [27]. ML was used in their systems, but they did not take into consideration people who have mobility limitations. Only two out of twenty systems show a significant lack of research used for machine learning that would change the reality of disabled people's lives for the better. Thus, the concluded future work in the context of this research and industry is to develop user-friendly smart home systems that are easy to use and being autonomous and adaptive by integrating machine learning models such as SVM and KNN algorithms to reduce the user interaction with the system as much as possible and utilize the acquired data from sensors and user-behavior (Zantalis et al., 2019). As the cornerstone of mind-controlled robotics, the Brain-Computer Interface (BCI) enables the development of technologies and solutions for mind-controlled smart homes (Bahri et al., 2014). As noted, the 20 systems for people with disabilities that were reviewed usually use wireless technology; 70% of them use Wi-Fi, and 30% of them use Bluetooth for ease of use.
Therefore, combining BCI with machine learning models can potentially help turn smart homes into intelligent homes.

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