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7 Deep brain monitoring using implantable sensor and microcontroller: a review

Abstract: The consequent evolution in technologies is reaching toward development in today's world. Microelectromechanical system (MEMS) technology is one of the emerging paradigms that signify continuous affection in healthcare systems. In hospitals, it is very necessary to constantly examine the health condition, monitor movements and physiological parameters of a patient. Collection of data, long-term connectivity of sensors with the network, data privacy maintenance, treatment over a number of neurological disorders and storage of diagnostic results is a very critical task in such organizations. Every bit of data is required to store in some specific format, and loss of data will generate the false result. To overcome such problem, different types of biomedical sensors and instruments are developed using MEMS technology. In this chapter, the deep brain monitoring using implantable sensors and microcontroller is used for treating number of neurological disorders, such as dystonia, tremor, Tourette syndrome, Parkinson's disease, cluster headaches and major depression. The technique includes electrodes embedded inside specific regions of brain and monitoring activity of patients remotely.

Keywords: Pulse generator (PG), Internet of everything (IoE), real-time brain monitoring, biomedical sensor, microcontroller, stimulation parameters

7.1 Introduction

Today's healthcare system is dominated with IoE (Internet of everything), which uses ambient intelligence (AmI) system. AmI is a collection of several smart devices that are active in the environment. They are well designed and developed in such a way that it automatically sync, control and manage connectivity with other sensor devices. Various applications depend on the sensors like a wireless body sensor network (BSN), biometric sensors, a wearable sensor, motion detection sensor and implantable sensors, these are developed using AmI and Internet of things (IoT). Advancement of a micro-electro-mechanical system (MEMS) technology leads to growth in these devices in recent years.

eHealth technologies give prominent features for minimizing healthcare expenses and enhance patient care in large scale. For measuring different parameters like pressure, temperature, and sugar level of humans, a "smart implant" technology is manufactured by the medical researcher, and also wearable sensors like smart watch, which is used to detect blood pressure (BP), heartbeat count

and posture aid. Biosensors could detect the internal state of the human body using electromagnetic radiation. Cancer cell within the body has been identified using nanotechnology. Because of enhancement in such sectors using MEMS technology [1], patients are not needed to visit the hospital on an everyday basis and it made really easy for caretakers to keep track of every activity of patients remotely.

Embedded devices are used to transmit and receive the signal to the devices present in the vicinity. Emerging evolution is occurring with the development of an IoE [2]. IoE has the ability to sense and collect data from around the world and share data across the network, where it is being processed and utilized sequentially. IoE is the collection of various devices, which are based on standard communication protocols. This technology extensively used to communicate about their internal and external environment between several device components. Communication between the devices is managed via secure networking and standard wired or wireless communication protocols. Embedded devices are capable to collect heterogeneous data from the proximity and can be processed, monitored and controlled remotely; these devices are components of IoE. Analysis of collected data locally is done using edge or mobile devices. IoE-based microcontrollers, microprocessors and sensors are integrated collectively to accomplish an appropriate task to minimize the human interaction with computers [2, 3].

In the United States, Medtronic is the world's largest medical technology organization. They have an advanced product named deep brain stimulator (DBS) device, which safely and efficiently manages tremor, rigidity and bradykinesia related to Parkinson's disease (PD). The drawback of this product is its high cost. At present, in India 35–45% of the population suffering is from PD, out of which 28–35% population cannot afford such high-value products [4]. An expected 30% of individuals with PD are analyzed before the age of 50.

In India, current research on DBS is carried out to provide proper medical care for PD patients [5–7]. DBS technique is a neurosurgical procedure in which electrodes are inserted inside specific region of the brain that connects to the device through an extension cable. This device helps in delivering electrical stimulation to those specific regions. Same as cardiac pacemaker shown in Figure 7.1, the technique uses a biomedical device called a pulse generator (PG) [8] to control the flow of electrical pulses inside the brain, thereby preventing the production of irregular nerve signal that causes PD. The general system for deep brain monitoring consists of an electrode implanted into the brain of the patient, which is connected to the implanted device located in the chest area or the abdomen through extension lead wire. The electrode and implanted device form a closed circuit. The device communicates with the external software application. The whole system runs on rechargeable battery that resides inside the implantable device and is periodically charged wirelessly from outside the body.

Figure 7.1: Cardiac pacemaker.

7.2 Related work

A brief glimpse of this study gives the overall idea of what exactly the e-health care system works to track and monitor the activities of patients remotely. The related work gives an overview of medical sensor-based different application such as various real-time e-healthcare application, remote monitoring of the patients, doctor–patient relationship management, “cloud network to store data related to the patient [22].” IoT cloud infrastructure and stimulation of pulse parameter using sensors. Finally, the summary of the survey has been carried out by reviewing related studies.

Behari et al. [4] focused on philosophical data on PD by investigating two risk components, as there is no data on transmission and control of Parkinson’s available in India. For the investigation, they studied few Parkinson’s patients and the same number of healthy people of the approximately same age. As PD is a rare disease and only occur at age above 60 years, it makes the study of risk components little difficult. Data for this chapter was collected by face-to-face interview with the patients. Information was classified based on the structure of the human population, various environmental components, history of depression and PD in the family and occupation. Authors set some rules to collect more accurate data. While studying, authors considered various use cases, which include case-matched control and age-matched control. Data were categorized with the help of different combinations of use cases. They also calculated McNemar chi-square value, which is a contingency table for paired data. Authors also calculated the p -value (potential risk component value). Their results showed that the probability of growing PD is more if

a person has PD in his family, if that person has a history of depression and is a male, and if he drinks well water, but spending time with pets and alcohol intake can reduce the chances of PD. They also found that a vegetarian diet, living in a population-less environment has no relation between these components and PD. According to the authors, these environmental components are also critical as genetic components.

Albayrak et al. [9] implemented the system based on an electronic survey for health care. This system is designed for early discovery of diseases like an epidemic disorder, which can be remotely monitored. The system dynamically activates to perceive the health status of patients. Doctors and health specialists can actively control and monitor the status of individuals by collecting the survey from individuals through electronic devices and create geographical risk maps. The proposed system has been tested in two sections: one is professional and another is an individual. In a professional method, the medical status evaluation has been carried out by clinicians as they distribute blueprint of reports to each patient through a software application. In an individual method, patients fill those reports and provide all the information about their health condition. Clinicians can easily evaluate the medical status of patients as per the response given by patients in the form of a report. Web-based application for monitoring of patients with PD was proposed by Chen et al. [10], wherein system provides an integration platform for services to execute at three different layers. Wearable sensors attached on patients' body gather accelerometer data. The web-based user interface permits two-route communication among patient and clinician hosts. Clinicians can get to the sensor and patient information and communicate to patients using the video conferencing. Authors evaluated latencies and bandwidth prerequisites at various levels of the framework. To guarantee estimation precision, all hosts synchronized to a similar network.

Chen et al. [11] studied and implemented a real-time remote monitoring system for PD patients with DBS. The system comprises four modules: a patient client, a physician client, video communication and a server station. This system provides web service on the Internet, the server station sets up a virtual connection between the patient and physician client. The physician client helped nurses to observe adequate data about the patients and giving alteration guidelines to the patient client through the wireless communication channel. After instruction execution, the patient client uploads the history records and results to the server station. Li et al. [12] proposed a pervasive healthcare monitoring system that can transmit patients' vital signs continuously to remote medicinal applications. For implementation authors focused on two modules: first the data acquisition module and second the data transmission module. The first module is responsible to collect data from biomedical sensors and forward it to the connector in short distance. In the second module, remote services receive sampled data from sensors and results are displayed to cardiologists in real time.

Monti et al. [5] investigated difficulties occurring in medical implantable devices operated at low-frequency range, which uses same wireless communication link for transmission of data and power. Authors examined wireless energy connection interface working in the MedRadio band. From the detailed analysis, authors illustrated the energy transfer efficiency of about 10.62%. Cubo et al. [6] present DBS therapy for PD, developed in order to reduce the seriousness of diseases by adjusting stimuli parameters. The authors described the methodology by simulation and clinical information acquired through medical imaging, electrical estimations and target side effect measurement. This system is developed using open- and closed-loop methodology. Stimulus parameters are manually set by doctors in open loop, whereas closed loop illustrates strategies used for evaluating motor symptoms and electrical estimations.

Smart DBS (SDBS) is implemented by Khan et al. [7] for evaluating the performance of stimulator. The essential functions of the SDBS incorporate movement recording, data interpretation, signal processing, stimulus waveform creation and optimization. Gope et al. [8] describe the importance of security requirements in BSN-based popular healthcare application. The authors proposed a protected IoT-based healthcare application using the authentication protocol and BSN, which helps in minimizing various existing security problems. BSN model includes two types of sensor networks (SNs): first is on-body SN, which provides a connection between wearable devices [19] and a coordinator; second is in-body SN, which provides a connection between implanted devices and the base station. Authentication protocol also includes two phases: first is the registration phase, where safety credentials are provided to the system through a secure channel; second is the anonymous authentication phase, where data transmission takes place.

Rahmani et al. [17] studied fog computing and its usage in IoT-based application. Smart gateway application offers several services at the network edge like processing, storing, compressing, standardizing and notifying. Fog computing forms an intermediary layer between sensor nodes and cloud for executing several services at the network edge. In processing service, a huge volume of sensitive data is controlled continuously in less time and response gets generated appropriately in different states. In filtering service, sensors receive multiple types of data to execute a proper processing algorithm at the network edge. In compression service, transmission latency and power consumption get reduced throughout the performance. Depending on the application requirement compression service is applied. In the fusion service, amount of data reduced by enabling the system efficiently. In analysis service, utilizing local data analysis at the endpoints increases the sensitivity of the application. It helps the system to recognize the emergency circumstances. In the local storage service, it ensures that the system can easily retrieve the data. An entry point should store the incoming data in nonvolatile memory of local storage.

Alelaiwi et al. [18] proposed smart services for the elderly and physically impaired individuals. The smart home system is designed and developed using

technologies like 5G network, cloud intelligence, BSN and wearable computing. This system is helped to provide an advantage over cost reduction, patient care remotely. Authors provided a solution to overcome some technical difficulties related to the smart home system. This system utilizes distributed computing and IoT framework to gather real-time data of environmental state from home for a secure living of patients. Systems generate the health report and broadcast alert message to family members and doctors. BSNs gather information regarding body temperature, electrocardiograph (ECG) and BP. The collected data was forwarded using Bluetooth technology to the cell phone and afterward, the same data was transferred through the Internet to a cloud server. Cloud server uses the central processing unit, a memory unit, a transmission unit, a graphical processing unit and different data mining algorithms.

Baktir et al. [14] proposed cloud computing (CC) and communication design for end-user devices. The active designed administration demonstrates all arrangements connected inside this system that completes an idea for programmable systems as software defined networking (SDN). To demonstrate the idea designed by the authors, they implemented a fall risk evaluation service. An experimental evaluation was carried out for accurate detection and performance-designed framework. The final output represents that the designed framework can be modified in real time and provides advantages over conventional methods. Mahmoud et al. [15] introduced CoT (cloud of things) models and the execution of model with human services also defined. Authors resolve missing institutionalization-related issues by model. Enhancement in quality of service and execution is needed for improving the productivity of the system. CoT is the combination of CC and the Internet. Table 7.1 illustrates the wireless communication standard protocol used in BSN.

Buston et al. [20] studied about the volume of tissues activated in different patients. They found out intersection between the activated volume of tissues and anatomical structures and compared the results with the actual clinical outputs. The system consists of three models. First is a 3D anatomical model that is derived from magnetic resonance imaging (MRI). Second is a finite element model (FEM), and third is volume of tissue activated (VTA) prediction deriving model. This approach is used to monitor subthalamic nucleus DBS in the patients suffering from PD. Here the postoperative MRI report is used to find out electrode location. Intensity values near to electrode are compared with slightly lower values of intensities. The first step is to correlate the MRI image and brain atlas wrapping. This is done using software tool from Surgical Navigation Technologies. The second step is to create biometric field model where variable resolution meshing algorithm is used to minimize the number of nodes and increase accuracy of the result. The third step is VTA prediction that is done using voltage solution of FEM. Clinical evaluation of patient is done followed by data analysis. The authors performed various clinical experiments held around 1-year post-medical procedure. Information is accounted for the left DBS anode. The patient's health was evaluated using two clinical

Table 7.1: Wireless communication protocol used in BSN [5, 13–16, 27, 28].

Parameter	Bluetooth (IEEE 802.15.1)	ZigBee (IEEE 802.15.4)	6lowPAN (IEEE 802.15.4)	Wi-Fi (IEEE 802.11)	NFC (ISO/IEC 18000–3)	LoRaWAN (IEEE 802.15.4)
Description	Exchange of data in small chunks	Intermittent data exchanges at low data rates	Exchange IPv6 packets over network	Exchange of large data in vicinity of wireless router	Exchange of data by putting devices very close together	Exchange of data over long distance with network server
Uses	IP configuration infrastructure	Low power digital radio signals	Header compression mechanism	Radiowaves for connectivity	Peer-to-peer communication	Chirped modulation format
Data rate	1 mbps	250 kbps	250 kbit/s	54–600 Mbit/s	100–420 kbps	0.3–50 kbps
Frequency	2.4 GHz	2.4 GHz	2.4 GHz	2.4 and 5 GHz	13.56 MHz (ISM)	433, 868, 915 MHz
Range	50–150 m	10–100 m	116 m	50 m	10 cm	2–5 km (urban area), 15 km (suburban area)

methods. Each analysis was conducted in the morning when the patient is in the vaccination state. During the first trials, the following conditions are required to produce monopolar stimulation: 2 Hz of frequency, 60 μ s of pulse width and 0 to -10 V of the reference voltage with 20 s of the time interval. During the second trials, reference voltage differs from 0 to -4.5 V with 130 Hz of frequency, 60 μ s of pulse width needed to produce monopolar stimulation.

7.3 Methodology of existing systems

Monti et al. [5] proposed a wireless connectivity provided by DBS for stimulating pulse. Implantable therapeutic devices perform an important function for treating diseases, for example, cardiovascular disease, neurological dysfunctions and intense type of diabetes. Wireless technologies [21] deliver an essential function to enhance the execution of these devices.

The wireless connection comprises two magnetically coupled resonators, that is, external resonator and implanted resonator illustrated in Figure 7.2. Both resonators possess a thickness of 1.18 mm and a frequency of 403 MHz. An external resonator occupies an area of 1.986×1.986 cm from the skin surface. An implanted resonator occupies an area of 1.594×1.594 cm that working at a profundity of 0.5 cm beneath a 0.2 cm layer of skin, a 0.2 cm-layer of fat and a 0.1 cm layer of muscle. The rate at which energy is consumed by the human body due to interaction with electromagnetic radiations is defined as specific absorption rate. It also defines the power dissipation rate per unit mass of tissue. Scattering parameters of a wireless connection were determined by methods of full wave stimulation.

Figure 7.2: Geometry of external and implantable resonator.

DBS therapy is facilitated by numerous communicating elements. An implanted pulse generator (IPG) that is precisely put under the skin close to the collarbone produces the electrical oscillations. These oscillations transmitted within a lead to the brain. The user interface is used for the doctor and the patients to impart the best possible settings to the PG and determine the real-time status. The authors define specification of stimulation parameters properly in the study [6]. IPG produces 10 V of amplitude, few milliamperes of current, 100–250 Hz of frequency and pulse width up to 60–120 μ s. A disease-specific stimulation target is characterized before the operation. With mathematical modeling, the preferred target must be prepared from medicinal pictures of the patient's brain. This can be performed by utilizing programming or physically.

Special conjectures must be made to measure neuron activation. In the stationary stimulation state, the thresholding of activation function and electric field are obtained. The threshold rate relies upon a few variables, that is, neuron thickness, neuron connectivity, pulse width and pulse polarity. Average thresholds utilized in the method are 20 mV for the activation function and 150–200 V/m for the electric field.

Authors developed the system using an open-loop and closed-loop model is depicted in Figure 7.3. In the open-loop stimulation, using the trial-and-error mechanism doctors physically adjust stimulus parameters. In the closed-loop stimulation, local field potential (LFP) desynchronization and impedance control approaches are reviewed. Computation of LFP in the region of the lead and evaluation of signal power in the beta-band is accomplished by LFP desynchronization method. The drawback of the LFP method is that this approach lacks additional functionality and power. Impedance measurements utilized in the evaluation of the electric properties of the lead–brain tissue interface.

As per the architecture of SDBS [7] designed by the authors, the intelligent anode can send important information to the outer controller through the secure wireless remote connection and the cathode. In this case, RFID (radiofrequency identification) is used as outer controller. The precise study explains system design methodology and its uprightness with the current RFID standard. The LTE/Wi-Fi connection provided to outer controller work acts as an entry point to/from the processing layer. The SDBS prototype configuration has two essential building blocks, one is an analog front end and another is digital core. Analog front end includes an antenna, network, modulator, demodulator and signals block, whereas design core includes implementation of the standard communication protocol, activity capturing and waveform generation methodology. Implementation of the digital core was carried out with the help of a well-known hardware module known as ARM CortexM0 and ATSAM20E18 microchip.

Generation of stimulus waveform is based on two techniques: one is the commands and another is arbitrary sampled information collected from the brain. The command-based technique of SDBS is demonstrated in Figure 7.4. The decoder translates the command sent by the outer controller and transfers pulse

Figure 7.3: Flowchart of open-loop and closed-loop model.

Figure 7.4: Block diagram of the stimulation generation [7].

amplitude, pulse frequency and stimulation duration parameters. Command base stores related parameters temporarily for smaller scale handling unit. In SDBS design, 8-bit resolution (digital–analog converter) DAC operating with the 1 MHz clock frequency and the reference voltage of 2.5 V, electrode uses 3.9 kHz of frequency to generate a waveform. The extreme value for pulse amplitude and pulse frequency is set as 2.5 V and 2.5 kHz, respectively. Neuroactivity recording and processing module comprises a CPU, processing unit and (analog–digital converter) ADC that is designed to record the LFP of the neural activity. Eight-bit ADC operating with the reference voltage of 2.56 V is required for converting analog signals to digital signals. The intelligent electrode produced a stimulation waveform parameter depicted in Table 7.2.

Table 7.2: Sinusoidal waveform parameters.

Parameters	Amplitude (mV)	Frequency (kHz)	No. of cycle
Test 1	800	2.5	5
Test 2	800	2.5	10
Test 3	800	2.5	20

Heart disease is a major cause of death nowadays. Immediate treatment to a patient suffering from heart disease is crucial. However, heart patients call the service themselves very late when the condition of disease is irreversible. This happens because the patient realizes the problem very late. Therefore, work needs to be done early for diagnosis of heart diseases. Internet of things solve this problem potentially. Patient's physical status is monitored by the physician continuously irrespective of where the patient is and what he is doing and based on the situation the physician will decide when to give treatment to the patient. Li et al. [12] have described IoT-based solution for constant monitoring of patients' physical parameters like BP, ECG and SpO₂. The authors described system architecture using four different transmission modes based on the medical need and feasibility of communication technologies [29].

A prototype implementation is done to represent the system data acquisition part or sensing layer comprises sensors worn or carried by patients. The sensor device is chosen based on parameters to be monitored and the sampling frequency of each parameter. Considering medical demands and a practical feasibility-monitoring scheme is decided. The sampling frequency of ECG signals is set to 128 Hz. Sensing of BP, pulse rate and SpO₂ level is carried out in the interval of 2 s. Testing of blood fat and blood glucose is conducted before and after a meal. The data transmission process is subdivided into two processes. Communication technologies required for these two subprocesses are different.

Data transmission from the sensor to the connector happens in short distance, which requires high bandwidth. Authors chose Bluetooth technology and smartphone as a connector for first subprocess. Once connector receives the data from the sensor it transfers these data to a remote site through another communication technology comprising second subprocess. The range of technology is a crucial part of the second subprocess. Cellular wireless technologies (GSM, GPRS) and wired technologies (ADSL) are used for the second subprocess. The data transmission [30] is performed in four modes: (a) in the first mode, continuous transfers of all data to the physician in real time are achieved. This is the highest monitoring level used for the patients who are at high risk of relapse by heart diseases. (b) In the second mode, a continuous transfer of data in the fixed time period is performed. Empirically heart attack takes place from 3 to 4 pm or within 2 h after waking up. Thus in this mode data transfer is continuously done during this period. (c) In the third mode, sampled data is sent to the connector using an event-triggered transmission mechanism. At connector, analysis of these parameters is performed and if the parameters are beyond the normal range it triggers an event. When an event triggered, transmission of data from the connector to the physician's server is carried out experimentally. (d) In the fourth mode, the physician's server receives the sensed parameters from the patient's body whenever they feel uncomfortable. As explained, the four modes are not quite the same as one another in the measure of information sent to the remote server, the necessity for network quality and the applicability for various kinds of patients.

Authors developed a system using MercuryLive architecture [10], which incorporates programming services running at three levels: a central server, patient's hosts and clinician's hosts. A central server provides a secure channel for data gathering and video forum service. The secure channel includes encrypted services, a secure sockets layer, Secure Shell and a virtual private network. In this layer, both patients and doctors can have direct access to the web server, database, data forwarding service and a video conferencing service. In the patient's host layer, doctors can set an ideal battery life status. As sensor information is being gathered, an information transfer demon keeps running in the interface background and then transfer the collected sensor information deftly to the central server. In clinician's host layer, doctors manage information-gathering sessions remotely. Doctors get the patient information and address patients utilizing the video conferencing administration if necessary. To describe MercuryLive architecture, authors surveyed latencies and bandwidth prerequisites at a various layer of the framework. Latency measurement depended on either timestamp gathered at each host or packet delivery at every MercuryLive layer. To guarantee estimation precision, framework clock was synchronized to a similar Network Time Protocol.

7.4 Components required for deep brain monitoring

This section describes the general components for brain monitoring e-healthcare system, which consists of implantable components and external components [6, 7]. There are three types of implantable components, namely, a lead, PG and an extension. Main external components for brain monitoring system are desktop application (DA), mobile application (MA) and wireless charger (WC). General architecture of PG for deep brain monitoring is shown in Figure 7.5. Description of each of the components is as follows.

Figure 7.5: Architecture of pulse generator (PG) for deep brain monitoring.

7.4.1 Implantable components

Electrode leads: The leads consist of four electrodes that provide stimulation parameters to a certain region of the brain [6]. These stimulation parameters are generated by PG. The leads are stereotactically introduced into the affected region of the brain as depicted in Figure 7.6.

Extension: The extension is a combination of wires. Electrode leads are attached with PG through an extension cable that provides an electrical path. The extension cable is embedded inside the scalp area, where it connects leads with an implantable device.

Figure 7.6: Placement of implantable components inside the human body.

PG: The PG is the heart of the DBS. Its main function is to generate stimulus parameters from an external software application over a wireless communication interface. It works from a rechargeable battery with a wireless charging interface. PG consists of the following parts: (a) stimulus generator, (b) rechargeable battery, (c) wireless charging interface, (d) wireless communication interface [31, 32] and (e) microcontroller for overall control and monitoring of the device [5, 6]. Specifications of PG are have programmable pulse parameters in the following ranges: (a) Pulse Amplitude – 0 to 5 V (voltage mode) adjustable in steps of 0.1 V and 0–20 mA (current mode) adjustable in steps of 0.1 mA, (b) pulse frequency – 200 Hz range approximately, (c) pulse width – 30–400 μ s, adjustable in steps of 10 μ s, electrode configuration – two leads for two brain hemispheres and four electrodes per lead. Pulse parameters are depicted in Figure 7.7.

Generation of waveform carried out using timer/counter function facilitated by the microcontroller. The timer in UP/DOWN mode is used for an electrode to generate pulse signals. Generation of waveform controlled by DAC with the reference voltage of 2.5 V named as (D0). Selection of electrode is controlled by MUX (M0). Once the timer started, 500 kHz of frequency is required to generate each pulse that takes around 1 μ s of the period. Timer consists of register, that is, A1 to A6 and B1 to B6 to store obtained values as represented in Figure 7.8.

Figure 7.7: Pulse generation parameters.

Figure 7.8: Pulse waveform generation by an electrode.

7.4.2 External components

DA: The DA is designed for use by a clinician, doctors and expertise to verify parameters settings. Using this software interface doctors can monitor the state of patients. This is designed to provide appropriate wireless interface for communicating with the implanted device.

Mobile application (MA): The mobile-based application communicates with PG via Bluetooth technology. Functionalities of this module are as follows: (a) patient or caregiver can control therapy state, (b) the user can check the status of the implanted battery and (c) allow the user to adjust the setting of pulse amplitude, pulse width and pulse rate within the clinician-prescribed limits.

WC: A wireless battery charger is used to charge the implanted device. Rechargeable frequency and time for WC is 1 day and less than 5 h, respectively. Algorithm 1 illustrates the DBS using MCU (microcontroller unit) system implementation initiating via software interface.

The advantage of the deep brain monitoring system is to enhance motor function, improve personal satisfaction and diminish medicine for patients. Treatment can enable patients to have an increasingly ordinary and autonomous way of life. It also helps in improving medicate-related confusions.

Algorithm 1: DBM using MCU system implementation.

Input: Clinician / Patient input parameter (Login details, Stimulus parameter setting)
Output: Actions (Therapy Program – START/STOP, Pulse Generator – Activate/Deactivate, External Components – Active/ Non-Active, Battery State – ON/OFF)
Begin: DBM using MCU
 Connect PG to external component using wireless communication protocol.
Case 1: START / STOP the therapy session
If Patient health status is abnormal **then**
 START therapy program session //via MA
Else If Patient health status is normal **then**
 STOP therapy program session //via MA
 End If
 End If
Case 2: Continuously monitor health of patient using software interface. //via MA and DA
Case 3: Wireless charging
If Battery State == Low **then**
 ON Battery Charging process using wireless charger
Else if Battery State == Full **then**
 OFF Battery Charging process
 End if
 End;
 End;

Table 7.3: Comparison between different existing systems.

Parameters	Aim	Technology	Advantage	Future scope
Albayrak et al. [9]	Providing health services instantly and efficiently via the transmission channel independent of space and time between health experts and the patient.	Bootstrap 3 CSS framework for front-end and PHP and MySQL for back end.	Provides active control over patients' own health status.	To generate geographical risk maps of diseases.
Chen et al. [10]	Data gathering using wearable sensors via a web interface.	Mercurylive architecture, Red5 server	Latencies and bandwidth at various levels of the framework is evaluated.	To store and display results of gathered data in a home setting.
Chen et al. [11]	Providing remote adjustment service and real time monitoring of PD patients with DBS.	Microsoft .NET framework, Bluetooth module, RF module	The framework provides remote control to caregivers and allows to check the historical record and also implement programming in real time.	To perform a first clinical trial under real time to test the usability and efficiency.
Li et al. [12]	Assist remote expert to be informed about patients' condition and diagnose serious conditions of heart diseases.	Bluetooth technology, cellular and wired technologies	Remote services receive sampled data from biomedical sensors and results displayed to cardiologists in real time.	To combine the data stream management system (DSMS) technologies into the existing system to improve its functions.
Cubo et al. [6]	Manipulation of stimulus pulse parameters using mathematical modeling, so patient can adjust stimulus parameters.	Low-frequency wireless technology.	Treatment over a number of neurological conditions using implantable sensors.	To work on safety measurements at a higher level.

(continued)

Table 7.3 (continued)

Parameters	Aim	Technology	Advantage	Future scope
Rahmani et al. [17]	Local data processing, data filtering, data compression, data fusion, data analysis.	Fog computing, 6LoWPAN, cloud server, eHealth gateway, geo-distributed fashion at the edge of the network.	Use of multiple data processing algorithms.	To improve API for gateway management using different transport layer protocol sockets for easy interoperability with different protocols.
Alelaiwi et al. [18]	Distributed computing and IoT real-time data collection of environmental state from home for a secure living of patients.	5G network, cloud intelligence, BSN, wearable computing	Generating health report (a) Monitoring of biosignals from BSN and smart phone, (b) context-aware sensing and (c) context-based recommendation. Alerting via broadcast message to family members and doctors.	To use different gadgets to recognize passionate information.
Baktir et al. [14]	Implemented load-balancing mechanism at edge servers. Real-time fall risk assessment using wearable sensors.	Machine learning model	Update and tracking the locations of the personal records regularly for each user.	To store data for long term.
Mahmoud et al. [15]	IoT cloud acts as middleware for managing cloud IoT foundations. IoT body sensors collect the required information, investigate and concocted in the cloud. CoT-based architecture model for isolation.	IoT cloud, Wi-Fi, WPAN	Helps to understand new technology for improvising healthcare sector.	To focus on an energy-aware allocation strategy for future research.
Buston et al. [19]	Using DBS to detect how much volume of tissue gets activated and calculate the range of pulse stimulation parameter.	3D nonlinear warping algorithm	User-friendly software interface developed for doctors and researcher to design their private DBS model.	To concentrate on treating other neurological diseases.

7.5 Observation

This section describes the general comparison between various existing applications using Table 7.3.

7.6 Conclusion

This study introduces the architecture and concept of deep brain monitoring and controlling using implantable sensors. IoE-based e-healthcare survey helps to deliver a unique medication approach to PD patients from India. The fundamental functions of the deep brain monitoring include patient activity monitoring, waveform generation using PG, therapy status checking, body movement controlling, information gathering, data forwarding, data analysis and many more. The existing application is developed to treat patients suffering from neurological disorder and research carried out by various researchers. These systems describe different methodologies used for healthcare applications that provide great practical significance approach in the treatment of PD patients. The research represents functionalities of the electrode and the stimulation pulse parameters in such a way that the DBS system is able to provide an adequate amount of stimulation without causing any harmful side effects to the tissue or patients body.

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