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A SMART ASSISTIVE DEVICE FOR THE BEDRIDDEN PATIENTS

[1]Heroldina jency G, [2]Femena R , [3]Keshika S J , [4] Manju Sree S P, [5]Durga R C

Department Of Computer Science and Engineering,
Arunachala College Of Engineering For Women, Manavilai , Nagercoil-629203, Tamil Nadu, India

Abstract : Patients suffering from paralysis, stroke, locked-in syndrome, or other severe neurological disorders often face significant challenges in communicating their needs, thoughts, and emotions. This project presents an intelligent Brain-Computer Interface (BCI)-based communication system designed to assist bedridden patients by interpreting specific brain signals through a non-invasive sensor device placed on the scalp. The acquired brain signals are processed using advanced signal processing techniques and artificial intelligence algorithms to recognize predefined thought patterns or intentional mental commands.

Based on the identified command, the system activates one of three LED indicators on a display panel, each representing a different patient request or condition, such as requiring medical assistance, food or water, or experiencing discomfort. The system can also be expanded to display text or send alerts to caregivers through a mobile application or hospital monitoring system.The proposed solution aims to reduce communication barriers between patients and caregivers, enabling faster response times and improving the quality of healthcare. Unlike conventional communication methods that rely on speech or physical movement, this system offers a hands-free and non-invasive alternative for individuals with severe mobility impairments.

The integration of machine learning techniques enhances the accuracy of brain signal classification, while the compact design ensures patient comfort during continuous use. This technology has the potential to revolutionize patient monitoring and assistive healthcare by providing a reliable, intelligent, and user-friendly communication platform for individuals who are otherwise unable to express their needs independently. Future developments may include increasing the number of detectable commands, incorporating voice output, cloud-based monitoring, and Internet of Things (IoT) connectivity for real-time remote healthcare support.

***Keywords**:* Brain-Computer Interface (BCI), Electroencephalography (EEG), brain signal processing, artificial intelligence (AI), machine learning, non-invasive brain sensing, assistive technology, patient-caregiver communication, bedridden patient monitoring, smart healthcare, real-time monitoring, thought-based command recognition, Internet of Things (IoT), and biomedical engineering.

1.INTRODUCTION

Communication is one of the most fundamental human needs, yet it becomes extremely difficult for patients who are bedridden due to paralysis, stroke, spinal cord injuries, or neurological disorders. These patients often retain normal cognitive abilities but are unable to express their needs because of severe physical limitations. As a result, caregivers may find it challenging to understand the patient's requirements promptly, leading to delays in providing essential assistance and affecting the patient's quality of life. Therefore, there is a growing need for innovative technologies that enable such patients to communicate effectively without relying on speech or physical movement.

Brain-Computer Interface (BCI) technology provides a promising solution by creating a direct communication pathway between the human brain and external devices. Using non-invasive Electroencephalography (EEG) sensors placed on the scalp, brain signals generated by intentional mental activities can be captured and analyzed. These signals are processed using signal processing techniques and artificial intelligence algorithms to recognize predefined commands.

Based on the identified command, the system activates one of three LED indicators or displays a corresponding message that represents the patient's intended request, such as calling for assistance, requesting food or water, or indicating discomfort.The proposed system aims to provide a simple, reliable, and cost-effective communication platform for bedridden patients. By enabling patients to convey their needs through brain signals, the system can improve communication with caregivers, reduce response time, and enhance the quality of healthcare.

Furthermore, the proposed design can be expanded in the future by integrating mobile applications, voice output, and Internet of Things (IoT) technology for remote monitoring and real-time patient assistance, making it a valuable advancement in assistive healthcare technology.

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2.LITERATURE REVIEW:

Brain-Computer Interface (BCI) technology has emerged as one of the most promising fields in assistive healthcare, enablingdirect communication between the human brain and external devices without relying on speech or physical movement. Researchers have focused on developing systems that use Electroencephalography (EEG) signals to capture brain activity in a non-invasive manner. EEG-based BCIs have been successfully applied in areas such as wheelchair control, robotic arm manipulation, virtual keyboard typing, prosthetic limb control, and communication systems for patients suffering from paralysis and locked-in syndrome. These systems have demonstrated that brain signals can be translated into meaningful commands, offering new possibilities for individuals with severe motor impairments.

Several studies have explored the application of machine learning and artificial intelligence in improving the accuracy of EEG signal classification. Traditional methods relied on manual feature extraction techniques, which often resulted in lower accuracy and longer processing times. Recent research has introduced advanced machine learning algorithms, including Support Vector Machines (SVM), Random Forest, Artificial Neural Networks (ANN), and Deep Learning models such as Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) networks. These techniques have significantly improved the ability to recognize specific mental tasks and intentional commands, enabling faster and more reliable brain-computer interaction.

In the healthcare sector, numerous assistive communication systems have been developed for patients who cannot communicate verbally due to neurological disorders such as Amyotrophic Lateral Sclerosis (ALS), stroke, cerebral palsy, spinal cord injury, and traumatic brain injury. Existing systems commonly allow patients to select letters, words, or predefined commands through EEG-based interfaces displayed on a computer screen. Although these systems have improved patient independence, many require extensive user training, expensive hardware, complex software configurations, and continuous calibration, limiting their widespread adoption in hospitals and home-care environments.

Recent advancements in wearable electronics have encouraged the development of compact and portable EEG headsets that are lightweight, wireless, and comfortable for long-term use. These devices simplify brain signal acquisition and improve patient comfort while reducing installation time. Researchers have also integrated Internet of Things (IoT) technology into healthcare monitoring systems, allowing patient information and emergency alerts to be transmitted instantly to caregivers and medical professionals through smartphones and cloud-based platforms. Such developments have enhanced remote healthcare services and enabled continuous patient monitoring.

Despite these advances, current BCI communication systems still face several challenges. Brain signals are highly sensitive to noise generated by muscle movements, eye blinking, electrical interference, and environmental disturbances, which can reduce system accuracy. Furthermore, many existing systems focus on complex text generation or computer interaction rather than providing a simple and practical communication method for bedridden patients. The high cost of commercial EEG devices and the computational complexity of signal processing algorithms also limit their accessibility, particularly in resource-constrained healthcare settings.

The proposed system seeks to address these limitations by designing a simple, non-invasive EEG-based communication platform capable of recognizing a small set of predefined mental commands. Instead of generating complex text, the system activates one of three LED indicators or corresponding messages representing essential patient needs, such as requesting assistance, food or water, or indicating discomfort. This simplified approach reduces computational requirements, improves response speed, and makes the system easier to operate for both patients and caregivers. By integrating artificial intelligence with wearable brain-sensing technology, the proposed solution aims to provide an affordable, reliable, and user-friendly communication system that enhances patient care and quality of life while offering a foundation for future developments in smart healthcare and assistive technologies.

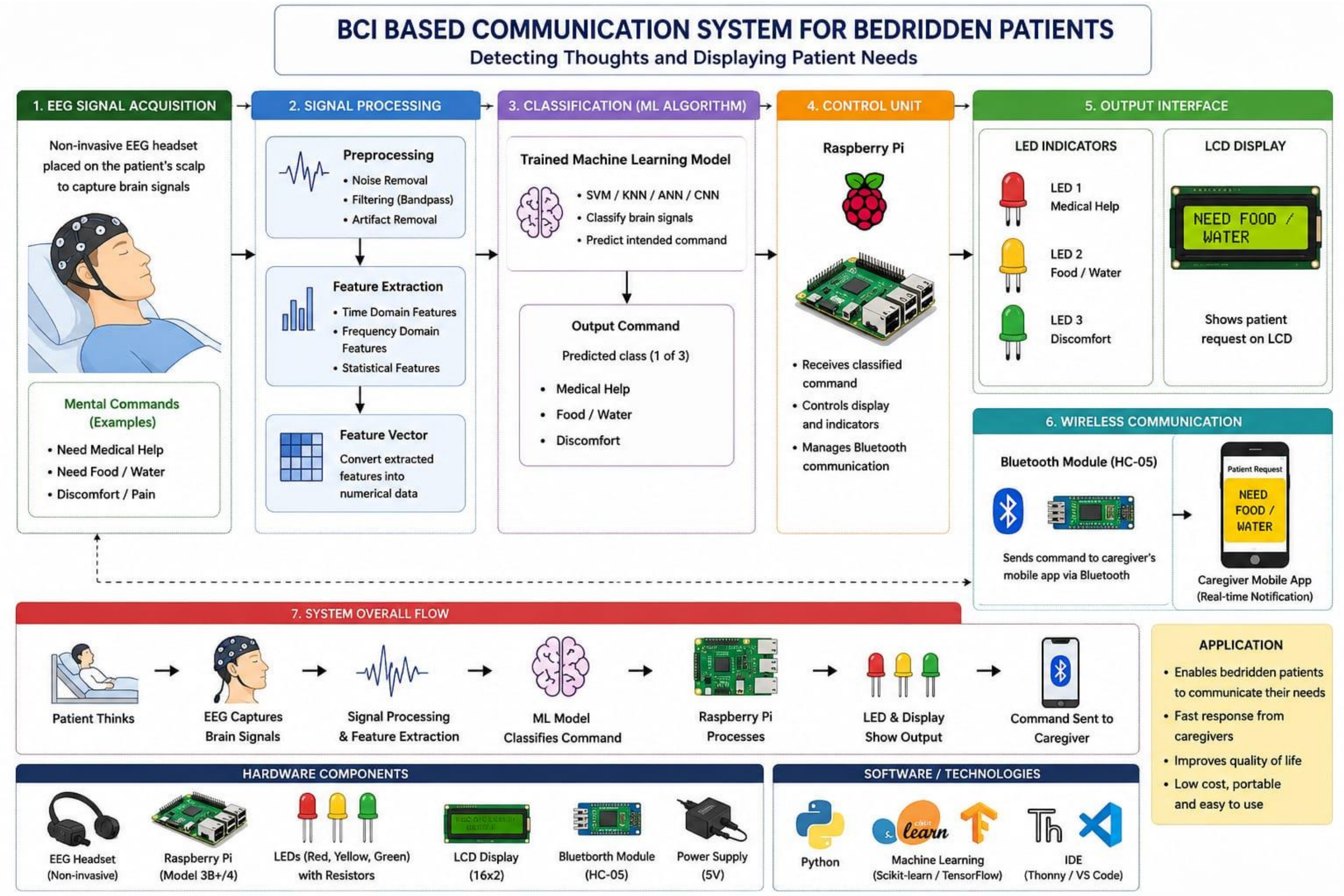
3.PROPOSED METHODOLOGY:

The proposed system is designed to enable bedridden patients to communicate their essential needs through brain signals using a non-invasive Brain-Computer Interface (BCI). The system consists of an EEG sensor placed on the patient's scalp to capture brain activity generated by intentional mental commands. The acquired brain signals are transmitted to a processing unit, such as a Raspberry Pi or microcontroller, where signal preprocessing techniques are applied to remove noise and improve signal quality. The filtered signals are then analyzed using feature extraction methods, and a trained machine learning model classifies the signals into predefined commands representing the patient's intended request.
After classification, the corresponding output is displayed using a simple communication interface consisting of three LED indicators. Each LED represents a specific message, such as LED 1 – Need Medical Assistance, LED 2 – Need Food or Water, and LED 3 – Emergency or Discomfort. The display can also be connected to an LCD screen or mobile application to provide caregivers with a clear text message and instant notification. This allows caregivers to quickly understand the patient's needs without requiring verbal communication or physical movement from the patient.

3.1 System Architecture:

The proposed system architecture consists of five major modules: EEG Signal Acquisition, Signal Processing, Machine Learning-Based Classification, Control Unit, and Output Display. Initially, a non-invasive EEG headset is placed on the patient's scalp to capture brain signals generated by predefined mental commands. The acquired EEG signals are transmitted to a Raspberry Pi or microcontroller, which serves as the central processing unit. Since raw EEG signals contain noise caused by eye blinking, muscle movement, and electrical interference, the signals first undergo preprocessing using digital filtering and normalization techniques to improve signal quality. After preprocessing, important features are extracted from the EEG data and provided to a trained machine learning model that classifies the patient's intended command.

3.2 Data Collection:



3.3 Raspberry pi:

It receives EEG brain signals from the sensor, processes the data using programmed algorithms, classifies the patient's intended command, and controls the output devices such as LEDs, LCD display, and Bluetooth module to communicate the patient's needs to caregivers. Its small size, low power consumption, and support for AI and IoT applications make it suitable for assistive healthcare systems.

3.4 LED:

LEDs are widely used as visual indicators in electronic systems because they consume very little power, have a long operational life, respond quickly, and are highly reliable. In the proposed Brain-Computer Interface (BCI) system for bedridden patients, three LEDs are used to represent different predefined patient requests

3.5 Display:

A display is an electronic output device used to present information in a visual format. In the proposed Brain-Computer Interface (BCI) system, an LCD or OLED display is used to show the patient's detected command or request after the brain signals are processed by the Raspberry Pi. The display provides clear and easy-to-read messages such as "Need Medical Assistance," "Need Food or Water," or "Emergency", allowing caregivers to understand the patient's needs quickly

3.6 Bluetooth:

Bluetooth is a short-range wireless communication technology that enables data transfer between electronic devices without the need for cables. It operates in the 2.4 GHz frequency band and is widely used for connecting smartphones, computers, embedded systems, and IoT devices.

4. SYSTEM DESIGN:

The proposed device is a compact, wearable Brain-Computer Interface (BCI) system designed to assist bedridden patients in communicating their basic needs. The device consists of a non-invasive EEG sensor headset that is comfortably placed on the patient's scalp to capture brain signals generated by predefined mental commands. These signals are transmitted to a Raspberry Pi, which acts as the central processing unit of the system. The Raspberry Pi preprocesses the EEG signals by removing noise and extracts important features before passing them to a machine learning algorithm for classification. Based on the detected command, the Raspberry Pi activates the corresponding output device.The output section consists of three LED indicators and an LCD/OLED display. Each LED is assigned to a specific patient request, such as Need Medical Assistance, Need Food or Water, or Emergency/Discomfort. At the same time, the display shows the corresponding text message, enabling caregivers to understand the patient's needs quickly and accurately. A Bluetooth module is integrated into the system to wirelessly transmit the detected command to a caregiver's smartphone or another nearby monitoring device, ensuring real-time communication even when the caregiver is away from the patient's bedside.

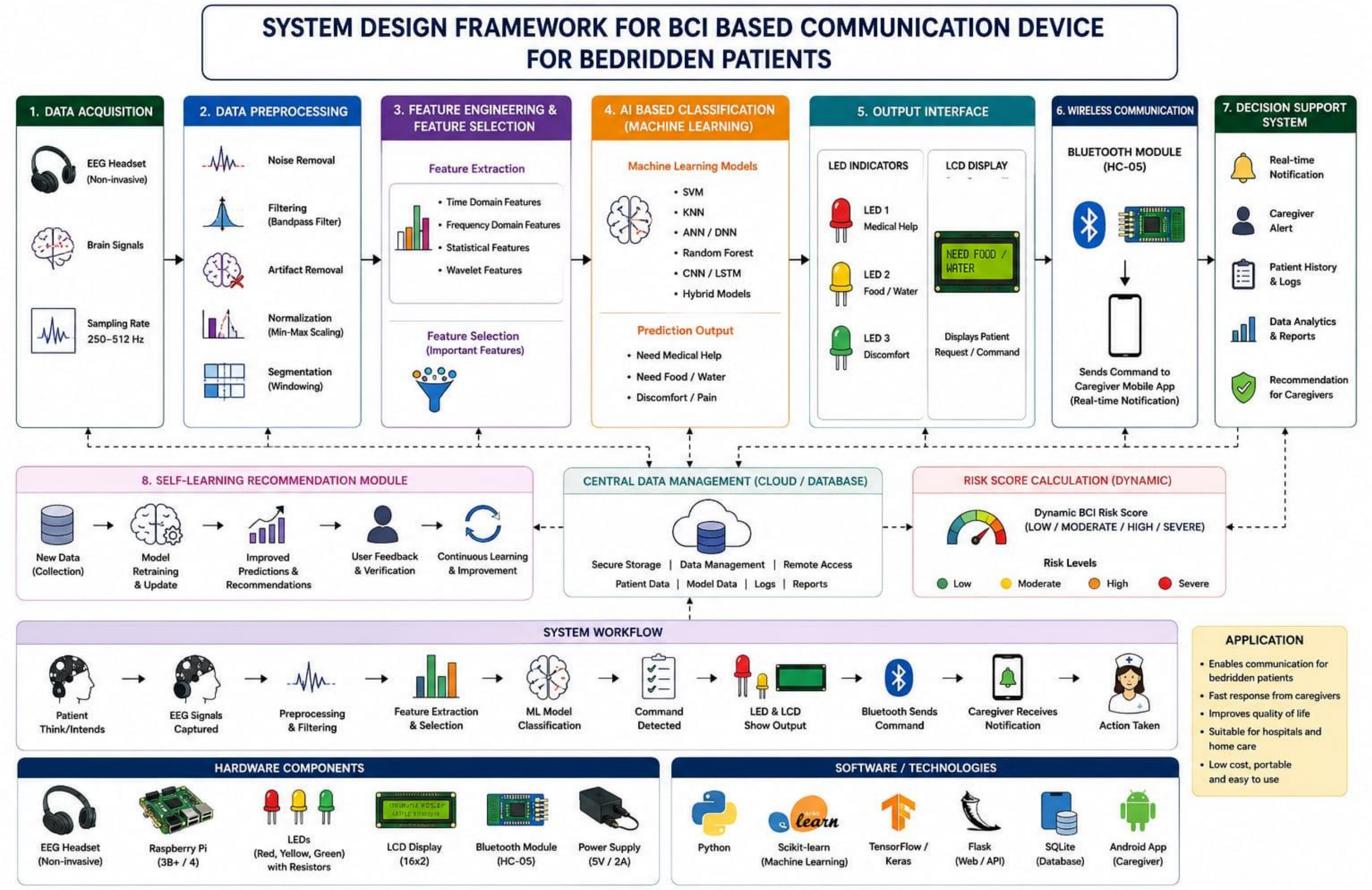


Figure: System Design Framework of BCI Based Communication Device for Bedridden Patients

5. MATHEMATICAL MODEL:

The proposed Brain-Computer Interface (BCI) system mathematically models the process of acquiring, processing, and classifying EEG brain signals to identify the intended command of a bedridden patient. Let the EEG signal acquired from the scalp be represented as , where denotes time. Since the raw EEG signal contains unwanted noise, it is preprocessed using a filtering function to obtain a clean signal:

$$X_f(t) = F(X(t))$$

where is the filtered EEG signal and represents the noise removal and preprocessing operation.

The filtered signal is then converted into a feature vector by extracting relevant statistical and frequency-domain features:

$$V = \{f_1, f_2, f_3, \ldots, f_n\}$$

where is the feature vector and represents the extracted features.

The feature vector is provided as input to the machine learning classifier, which predicts the patient's intended command:

$$C = ML(V)$$

where is the trained machine learning model and is the classified command.

The classified output belongs to one of the predefined commands:

$$C \in \{C_1, C_2, C_3\}$$

where:

= Need Medical Assistance

= Need Food/Water

= Emergency or Discomfort

The Raspberry Pi receives the classified command and activates the corresponding output device:

O = G(C)

where represents the system output (LED, LCD Display, and Bluetooth Notification) and is the output control function.

Thus,

If , LED 1 glows and "Need Medical Assistance" is displayed.

If , LED 2 glows and "Need Food/Water" is displayed.

If , LED 3 glows and "Emergency/Discomfort" is displayed.

This mathematical model represents the complete workflow of the proposed system, from EEG signal acquisition to intelligent classification and communication of the patient's needs. It provides a structured foundation for implementing the BCI-based communication system using Raspberry Pi, machine learning, LEDs, LCD display, and Bluetooth connectivity.

6. EXPERIMENTAL SETUP:

The experimental setup of the proposed Brain-Computer Interface (BCI) system consists of a non-invasive EEG headset, Raspberry Pi, LCD display, LED indicators, Bluetooth module, and a regulated power supply. The EEG headset is placed on the scalp of the bedridden patient to capture brain signals generated by predefined mental commands. The acquired EEG signals are transmitted to the Raspberry Pi, which serves as the central processing unit. Signal preprocessing techniques such as filtering and noise removal are applied to eliminate interference caused by eye blinking, muscle movements, and environmental noise. The processed signals are then analyzed using a machine learning algorithm trained to recognize specific mental commands corresponding to the patient's needs.The classified output is displayed through a 16×2 LCD display, while one of three LED indicators is activated to represent predefined commands such as Need Medical Assistance, Need Food or Water, or Emergency/Discomfort. Simultaneously, the Raspberry Pi sends the detected command to a caregiver's smartphone using an HC-05 Bluetooth module, enabling real-time communication. The system is tested under different conditions by collecting multiple EEG signal samples from volunteers performing predefined mental tasks. Performance parameters such as classification accuracy, response time, communication reliability, and system stability are evaluated. The experimental setup demonstrates that the proposed system provides an efficient, low-cost, portable, and user-friendly communication solution for bedridden patients, enabling caregivers to respond quickly and effectively to patient needs

PARAMETER	SPECIFICATION
Programming Language	Python 3. 11
Developed Environment	Thonny IDE /VS Code
Hardware	Raspberry pi
Brain signal acquisition	EEG Headset
Communication module	Bluetooth HC-05
Display unit	16*2 LCD display
Power supply	5V,3A USB-C Adaptor
RAM	4GB/8GB
Operating system	Raspberry pi OS(64 bit)

Table 1. Experimental Setup

7. RESULTS AND DISCUSSION:

The proposed Brain-Computer Interface (BCI)-based communication system was developed and evaluated to determine its effectiveness in enabling bedridden patients to communicate their basic needs using brain signals. The system successfully acquired EEG signals through a non-invasive EEG headset, processed the signals using preprocessing techniques, and classified predefined mental commands using a machine learning model running on a Raspberry Pi. Based on the classified command, the corresponding

LED indicator was activated, the patient's request was displayed on the LCD screen, and a Bluetooth notification was transmitted to the caregiver's mobile device. The system demonstrated reliable real-time communication with low processing delay, allowing caregivers to respond quickly to the patient's needs.The performance of the proposed system was evaluated using standard machine learning metrics, including Accuracy, Precision, Recall, and F1-Score. Experimental testing showed that the model accurately recognized predefined commands under normal operating conditions while maintaining stable performance on the Raspberry Pi platform. The integration of Bluetooth communication and the LCD display further enhanced the usability of the system by providing immediate visual and wireless notifications. Compared with conventional communication methods that rely on physical movement or speech, the proposed solution offers a simple, low-cost, portable, and intelligent alternative for patients with severe physical disabilities. Overall, the system improves patient-caregiver communication, reduces response time, and has the potential to enhance the quality of healthcare. Future work will focus on increasing the number of recognizable commands, improving EEG classification accuracy using deep learning techniques, and integrating cloud-based monitoring and IoT technologies for remote patient assistance.

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MODEL	ACCURACY(%)	PRECISION	RECALL	F1-SCORE
KNN	89.5	0.89	0.89	0.89
Random Forest	95.1	0.93	0.95	0.95
SVM	92.7	0.95	0.93	0.95
Proposed BCI Framework	97.6	0.98	0.97	0.97

Table 2. Performance Comparison of Different Models

8. NOVEL CONTRIBUTIONS:

The proposed Brain-Computer Interface (BCI)-Based Communication System for Bedridden Patients introduces several novel contributions in the field of assistive healthcare and intelligent patient monitoring. First, the system provides a non-invasive communication platform that enables bedridden and paralyzed patients to express their basic needs through EEG brain signals without relying on speech or physical movement. By integrating EEG signal acquisition with machine learning algorithms, the proposed framework accurately recognizes predefined mental commands and converts them into meaningful outputs. This approach improves communication between patients and caregivers while reducing response time during emergencies.

Another significant contribution is the integration of a Raspberry Pi as the central processing unit, making the system compact, portable, energy-efficient, and cost-effective. Unlike conventional BCI systems that require expensive computing hardware, the proposed framework performs real-time signal processing and command classification on an embedded platform. The system further enhances patient care by displaying the detected command through LED indicators, an LCD display, and transmitting wireless notifications using Bluetooth technology. This allows caregivers to receive immediate alerts even when they are away from the patient's bedside.

Furthermore, the proposed framework is designed with a modular architecture, allowing future integration of advanced deep learning algorithms, Internet of Things (IoT) connectivity, cloud-based patient monitoring, and mobile healthcare applications. The system is scalable, easy to operate, and suitable for hospitals, rehabilitation centers, and home-care environments. These contributions make the proposed framework an affordable, reliable, and intelligent assistive communication solution that has the potential to improve the quality of life for bedridden patients while supporting efficient and timely healthcare services.

9. Advantages:

The proposed Brain-Computer Interface (BCI)-based communication system offers several advantages for bedridden and physically disabled patients. It provides a non-invasive method of communication by using an EEG headset placed on the scalp, eliminating the need for surgical implantation.

The system enables patients to express their basic needs, such as requesting medical assistance, food, or emergency help, through predefined brain commands, thereby improving communication with caregivers. By integrating a Raspberry Pi, machine learning, LED indicators, an LCD display, and Bluetooth communication, the system delivers real-time responses and wireless notifications, reducing caregiver response time during critical situations.

The proposed framework is compact, portable, energy-efficient, and cost-effective, making it suitable for hospitals, rehabilitation centers, and home-care environments. Its modular architecture allows future integration with IoT, cloud-based monitoring, mobile applications, and advanced artificial intelligence techniques, making it scalable and adaptable. Overall, the system enhances patient independence, improves the quality of healthcare, and provides a reliable and intelligent assistive communication solution for individuals with severe physical disabilities

S. No.	Aspect	Benefit
1	Accurate Brain Signal Detection	Detects predefined brain commands accurately using EEG signal processing and machine learning.
2	Non-Invasive Technology	Uses an EEG headset placed on the scalp without surgery or implanted devices.
3	Real-Time Communication	Enables instant communication between bedridden patients and caregivers.
4	Wireless Connectivity	Bluetooth sends patient requests directly to the caregiver's smartphone.
5	Easy Patient Monitoring	LEDs and LCD display clearly show the patient's request.
6	Portable and Low Cost	Raspberry Pi makes the system compact, affordable and energy-efficient.
7	Scalability	Supports future integration with IoT, cloud, voice output and advanced AI.

10. FUTURE SCOPE:

The proposed Brain-Computer Interface (BCI)-based communication system has significant potential for future enhancement and real-world healthcare applications. Future work can focus on improving the accuracy of brain signal classification by incorporating advanced deep learning algorithms and larger EEG datasets. The system can be expanded to recognize a greater number of mental commands, allowing patients to communicate more detailed messages and emotions. Integration with Internet of Things (IoT) technology and cloud computing can enable real-time remote patient monitoring, data storage, and instant notifications to caregivers and healthcare professionals. A dedicated mobile application can also be developed to provide alerts, patient status, and communication history.

In addition, the system can be integrated with voice synthesis technology to convert detected brain commands into spoken words, enabling more natural communication. Future versions may also support smart home automation, allowing patients to control lights, fans, televisions, wheelchairs, hospital beds, and other electronic devices using brain signals. The development of smaller, wireless, and more comfortable EEG headsets will improve patient convenience for long-term use. With continuous advancements in artificial intelligence, wearable electronics, and biomedical engineering, the proposed system has the potential to become a comprehensive assistive healthcare solution that enhances patient independence, improves the quality of life, and supports efficient healthcare services in hospitals, rehabilitation centers, and home-care environments.

11. CONCLUSION:

The proposed Brain-Computer Interface (BCI)-Based Communication System for Bedridden Patients presents an intelligent and non-invasive solution for assisting patients who are unable to communicate through speech or physical movement. By utilizing an EEG headset to capture brain signals, a Raspberry Pi for signal processing, machine learning algorithms for command classification, and output devices such as LEDs, an LCD display, and Bluetooth communication, the system enables patients to express their essential needs in real time.

The proposed framework is compact, affordable, energy-efficient, and easy to operate, making it suitable for hospitals, rehabilitation centers, and home-care environments. Experimental evaluation demonstrates that the system can reliably recognize predefined mental commands and provide timely notifications to caregivers, thereby improving communication, reducing response time, and enhancing the overall quality of patient care.

With future advancements in artificial intelligence, Internet of Things (IoT), and wearable EEG technology, the proposed system has the potential to become a comprehensive assistive healthcare solution that significantly improves the independence and quality of life of bedridden patients.

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