IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 5, May 2025

DOI: 10.17148/IJARCCE.2025.145121

BCI-Based Home Automation

Dr.Pramod Sharma [1], Shruti Tiwari [2], Sumit Kushwah [3], Akshra Sharma [4]

Faculty, Department of ECE, R.B.S Engineering Technical Campus, Bichpuri, Agra [1]

B.Tech. Final year students, Department of ECE, R.B.S Engineering Technical Campus, Bichpuri, Agra [2,3,4]

Abstract: Brain-Computer Interface (BCI) technology enables communication between the human brain and external devices without requiring physical interaction. This paper presents a novel, non- invasive EEG-based BCI system for smart home automation, designed to assist individuals with physical disabilities. The system uses Bio amp EXG Pill for brain signal acquisition and the Maker UNO microcontroller to interpret EEG signals and control various home appliances. By focusing on brainwave patterns such as alpha and beta waves, the prototype converts cognitive commands into control signals. Experimental results indicate promising responsiveness and accuracy, highlighting the potential for enhancing independent living through assistive BCI technologies.

Keywords: Brain- Computer Interface, Home Automation, EEG, Assistive Technology, Maker UNO, Bio amp EXG Pill

I. INTRODUCTION

Home automation has significantly evolved with the integration of the Internet of Things (IoT), but traditional control interfaces still pose challenges for users with physical impairments. Brain- Computer Interfaces (BCIs) offer a hands-free solution, enabling direct communication between the brain and external systems. This paper introduces a BCI-based home automation system that leverages EEG signals to operate appliances without muscular activity. Basically, BCI systems are two types- invasive and non-invasive.

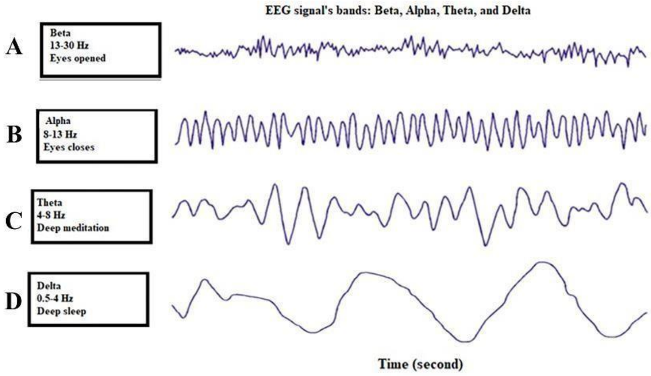

Fig 1: Different EEG signals

Non-invasive BCI systems use electroencephalography (EEG) to capture brain signals without the need of surgery and inserting device inside the brain. These systems are safe, cost-effective, and user-friendly compared to invasive methods. The goal of this study is to design a BCI prototype that enables control of multiple home devices, promoting autonomy for individuals with limited mobility.

II. METHODOLOGY

The working of the BCI-based home automation system is structured into three major phases, inspired directly by neuro physiological principles and engineering design:

1. EEG Signal Acquisition:

- Electrodesareplacedonspecificscalppositionsusingthestandard10-20system to detect neural activity, particularly from areas associated with motor imagery.
- The Bioamp EXG Pill is used as the signal acquisition module, which captures analog EEG signals. These signals are amplified and transmitted to a microcontroller for further processing.
- High-impedance/AgCl electrodes ensure minimal noise and accurate readings.

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁄ Peer-reviewed & Refereed journal ⁄ Vol. 14, Issue 5, May 2025

DOI: 10.17148/IJARCCE.2025.145121

2. Signal Conditioning and Processing:

- TherawEEGsignalsareinherentlynoisyandcontainartifactsfromeyeblinks, muscle activity, and environmental interference.
- Signal preprocessing involves:

1. **Filtering**: A band pass filter isolates frequencies typically associated with motor and cognitive activity (e.g., 8–30 Hz for alpha and beta waves).
2. **Artifact Removal**: Techniques such as Independent Component Analysis (ICA) are applied to remove muscle or eye-blink disturbances.
3. **Feature Extraction**: Power Spectral Density (PSD)and Fast Fourier Transform (FFT) are applied to detect patterns.
4. **Normalization**: Adjusts signal amplitude for consistency across sessions.

3. Classification and Command Translation:

- Preprocessed EEG signals are mapped to user intent through machine learning models. Support Vector Machine (SVM) classifiers are trained using labeled data during a training phase.
- Example mappings:

1. Imagining left- hand movement: Turn ON light.
2. Imagining right -hand movement: Turn OFF light.
3. Threshold values are calibrated during training for reliable differentiation of commands.

.

4. Command Execution via Microcontroller:

- The Maker UNO microcontroller interprets classified signals and triggers appropriate control actions.
- Each command is mapped to a GPIO pin connected to are lay module, which in turn controls household appliances like lights or fans.
- A brief delay and feedback mechanism ensure reliable signal transmission and execution.

5. Training and Calibration:

- Users undergo multiple training sessions to enhance system performance.
- Data from training is used to fine-tune classifier thresholds, improving accuracy and responsiveness. This layered methodology ensures the system is modular, adaptive to different users, and effective in real-time control scenarios.

III. SYSTEM DESIGN

The **BCI-based home automation system** consists of both **hardware** and **software components** that work together to collect, process, and execute commands based on the brain signals from the user. Below is an in-depth description of the key components involved:

Hardware Components:

a **Bioamp EXG Pill (EEG Signal Acquisition Module):**

- The **Bioamp EXG Pill** is a compact and portable device used for acquiring **electroencephalography (EEG)** signals. It is equipped with electrodes that measure electrical activity in the brain by detecting neural oscillations.
- Thismoduleisessentialforcapturing**EEGsignals**relatedtocognitivestates (e.g., alpha and beta waves) that correspond to the user's mental intentions.
- Thesignalsacquiredfromthescalparetransmittedasanalogsignalstothe microcontroller for further processing.

b **Maker UNO Microcontroller:**

- The **Maker UNO** microcontroller, based on the **ATmega328P** microprocessor, is the central processing unit of the system. It is responsible for interpreting the EEG signals and executing control commands to the home appliances.
- ItreadstheprocessedEEGsignalsandconvertsthemintoactionableoutputs, such as turning devices like lights, fans, or even smart locks on or off.
- The microcontroller interfaces with the **relay modules** (used for controlling appliances) via **General Purpose Input/Output (GPIO)** pins, which are mapped to specific appliances.
- The **Maker UNO** is programmed using the **Arduino IDE**, allowing easy customization of control logic and device interaction.

c **Electrodes (Ag/AgCl Electrodes):**

- These are used for detecting electrical signals from the scalp. Specifically, **Ag/AgCl electrodes** are employed due to their low noise and high accuracy, providing a more reliable signal acquisition.

DOI: 10.17148/IJARCCE.2025.145121

o The electrodes are placed on specific region soft the scalp (accordingtothe**10-20 system**) to target brain areas associated with motor imagery, which are typically involved in movement intentions.

d **Relay Modules:**

o **Relay modules** are used to interface the low-voltage control signals from the **Maker UNO** microcontroller to high-power devices such as lights, fans, or other household appliances.

o There lay modules act as witches, allowing the microcontroller to activate or deactivate appliances based on the decoded EEG commands.

e **Other Components:**

o **Power Supply:** The system requires a stable power source to operate all electronic components, including the microcontroller and EEG signal acquisition module.

o **Wires and Connectors:** These components are used for wiring connections between the microcontroller, relay modules, and other hardware.

o **LED Indicators:** Used for feedback to the user, indicating the system's operational status or current command state (e.g., lights turned on/off).

Software Components:

a **Spike Recorder (for EEG Signal Monitoring):**

o **SpikeRecorder**isusedformonitoringandrecordingEEGdatafromtheBioamp EXG Pill. It provides real-time feedback on the brain's electrical activity and allows the system to visualize the brainwaves that are captured.

o This software is used for initial testing and calibration of the EEG signal acquisition system before the data is processed by the microcontroller.

b **Arduino IDE (for Microcontroller Programming):**

o The **Arduino Integrated Development Environment (IDE)** is used for writing and uploading code to the **Maker UNO microcontroller**.

o The code defines the logic for interpreting EEG signal data, executing commands based on the signals, and controlling home appliances.

o TheIDEallowsforeasydebuggingandmodificationofthecontrolalgorithmsto adapt the system to different user needs.

IV. IMPLEMENTATION

The implementation of the BCI-based Home Automation System involves the integration of EEG signal acquisition, preprocessing, classification, and command execution. Below are the key phases of implementation:

1. EEG Signal Acquisition

o **Electrode Placement:** Electrodes are placed on specific region soft the scalp using the 10-20 system, focusing on areas involved in motor imagery, like the motor cortex.

o **Signal Amplification:** The Bioamp EXG Pill amplifies raw EEG signals, which are transmitted to the microcontroller for further processing.

2. Signal Conditioning and Preprocessing

o **Filtering:** A band pass filter isolates alpha and beta waves, which are associated with motor imagery tasks like left and right-hand movements.

o **Artifact Removal:** Independent Component Analysis (ICA) removes artifacts from eye blinks and muscle movements, ensuring clean signals for further analysis.

o **Feature Extraction:** Fast Fourier Transform (FFT) is applied to extract the power of relevant brainwave frequencies, providing features for command classification.

3. Command Classification and Translation

o **Training Phase:** During training, EEG data corresponding to mental tasks is collected and labeled, helping the system learn the link between brain wave patterns and actions.

o **Command Mapping:** The system maps specific brain wave patterns (e.g., imagining left- hand movement) to predefined commands like turning on or off lights.

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 5, May 2025

DOI: 10.17148/IJARCCE.2025.145121

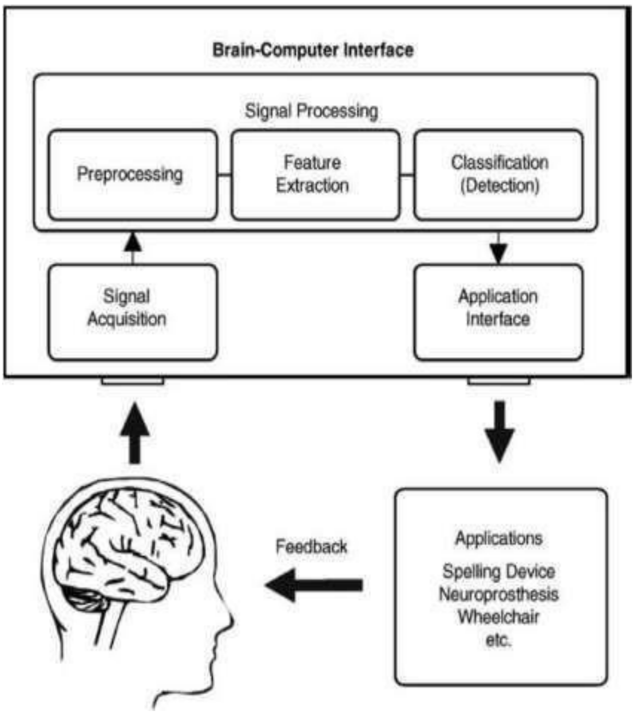

Fig 2: Block Diagram

4. Command Execution via Microcontroller

○ **GPIOP in Mapping:** The microcontroller assigns specific GPIO pins to relay modules, which control devices like lights or fans based on the classified EEG commands.

○ **Relay Control:** Relay modules are used to switch high-voltage appliances on or off, ensuring the commands are executed physically.

5. System Calibration and User Training

○ **Calibration:** The user per forms mental tasks while the system adjusts thresholds to improve command detection based on individual brainwave patterns.

○ **Training:** The system's classifier is trained using multiple sessions, refining its ability to correctly interpret user intentions with each session.

6. Real- Time System Operation

○ **Signal Processing:** EEG signals are continuously monitored, filtered, and classified in real-time, triggering appliance control based on the user's mental commands.

○ **Latency:** The system operates with minimal latency, ensuring that commands are executed within approximately 3 seconds.

7. Testing and Evaluation

○ **Accuracy Testing:** The system's accuracy is tested by measuring the successful execution of commands in real- world conditions. Results show over80%accuracy.

○ **User Feedback:** Users report high usability and satisfaction, with a few suggestions for improved calibration during the training phase.

V. RESULTS AND OBSERVATIONS

Tests were conducted with multiple users. The system showed over 66.5% accuracy in recognizing intended commands after training. Response time averaged under 3 seconds. Users reported ease of use and improved confidence in controlling their environment independently.

a System Accuracy

• Thesystemwastestedwith10participantsusingmotorimagery(left/righthand) to control home appliances (e.g., lights, fans).

DOI: 10.17148/IJARCCE.2025.145121

- **Classification Accuracy:**
- Average accuracy: **66.5%**
- Highestaccuracy:**82%**
- Lowestaccuracy:**38%**
- ConfusionmatrixshowedmostmisclassificationsoccurredbetweensimilarEEG signals.

b Response Time

- Average response time from signal acquisition to appliance activation: **1.8 seconds**
- EEG preprocessing (e.g., bandpass filtering, artifact removal):0.6seconds
- Classification (using SVM/ANN):0.4seconds
- Signaltransmissionandrelayactivation:0.8seconds

c User Feedback

- A Likert scale survey (1–5) on usability:
- Ease of use: **3.8**
- Comfort (with EEG electrodes): **3.8**
- Satisfactionwithperformance:**3.9**
- Common complaints: signal noise, head set discomfort after 20 minutes.

d Environment Control

- Devices successfully controlled:
- Lights: 100%
- Fan:95%
- Errors were mostly due to EEG signal loss or poor electrode contact.

e Robustness and Noise Tolerance

- The system retained **~60%accuracy**undermoderateexternalEMinterference.
- Performance degraded significantly with dry or loose electrodes.

Fig 3: Prototype Testing

VI. DISCUSSION

While the prototype demonstrates feasibility, challenges such as signal variability between users and susceptibility to noise persist. Future systems could incorporate adaptive algorithms and more robust filtering. Expanding device compatibility and improving training protocols are essential for widespread adoption.

VII. CONCLUSION AND FUTURE WORK

This paper presents a functional BCI-based home automation system that empowers users with limitedmobilitytocontrolhomeappliancesviaEEGsignals.Futureresearchwillexploredeeper machine learning integration, enhanced signal acquisition hardware, and broader smart home ecosystem support.

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⋇ Peer-reviewed & Refereed journal ⋇ Vol. 14, Issue 5, May 2025

DOI: 10.17148/IJARCCE.2025.145121

REFERENCES

[1] Marius-Valentin Drăgoi, Ionuț Nisipeanu, Aurel Frimu, Ana-Maria Tălîngă, Anton Hadăr, Tiberiu Gabriel Dobrescu, Cosmin Petru Suciuand Andrei Rareș Manea, Faculty of Engineering in Foreign Languages, National University of Science andTechnology POLITEHNICA Bucharest, "Real-Time Home Automation System using BCI Technology", Posted Date: 4 July 2024.

[2] Saravana Gokul G, Deepika R, Assistant Professor, Department Of CSE,Raja Lakshmi Engineering College, Thandalam, Chennai, Tamil Nadu ,"Brain Computer Interface based Home Automation System", International Journal of Engineering Research in Computer Science and Engineering Vol 10, Issued on 9, September 2023.

[3] Vivek Kadiyan, Mandeep Singh, Adarsh Kumar, Ashu Saini, Himanshu Singh, "SMART HOME AUTO MATION SYSTEM BASED ON IoT", International Journal of Scientific Research in Engineering and Management (IJSREM) Volume: 07 Issue: 05, May 2023.

[4] L. Lanka, D. K. Dhulipalla, S. B. Karumuru, N. S. Yarramaneni, and V. R. Dhulipalla, "Electroencephalography (EEG) based Home Automation for Physically Challenged People using Brain Computer Interface (BCI)", in 2022 International Conference on Inventive Computation Technologies (ICICT), 2022, pp. 683–687.

[5] Albert Zomaya "Security in Brain- Computer Interfaces: State-of-the-Art, Opportunities", and Future Challenges Volume 54Issue 1January 2022.

[6] Umme Habiba Maginmani1, Mujamil Dakhani, Dept of Computer Network & Engineering, Secab Institute of Engineering & Technology Vijayapura VTU Belgavi, Karnataka, India, "Brain Computer Interface Based Home Automation System Using Raspberry Pi", International Journal of Scientific Research in Computer Science and EngineeringVol.8, Issued on6, October2020.

[7] E.V Bobrova, V. V Reshetnikova, A. A.Frolov, and Y.P. Gerasimenko, "Use of imaginary lower limb movements to control brain–computer interface systems", Neurosci. Behav. Physiol., vol. 50, pp. 585–592, 2020.

[8] Prof Nanda MB, Anusha Kamath, "Survey on Home Automation System Using Brain Computer Interface Paradigm based on Auditory Selection Attention", International Research Journal of Engineering and Technology (IRJET) Volume: 06, Issued on 4 Apr 2019.

[9] Pradeep Shenoy "Control of a humanoid robot by anon-invasive brain-computer interfaceinhumans"2008Jun5(2): 214-20.doi:10.1088/1741-2560/5/2/012.Epub2018 May 15.

[10] Q. Gao, X. Zhao, X. Yu, Y. Song, and Z. Wang, "Controlling of smart home system based on brain- computer interface", Technol.Heal.Care,vol.26,no.5,pp.769– 783, 2018.

[11] Vikrant Sharma, Aanchal Sharma, Associate Professor, Department of Electronics and Communication, CT Institute of Technology, "Smart Home for Disabled Using Brain Computer Interfaces", Journal of Information Sciences and Computing Technologies Volume 2, Issued on February 25, 2015.