HBCI_User_Manual

The importance of high-quality software tools for advancing EEG research cannot be overstated. However, to our knowledge, there is a lack of an open-source EEG software platform that can cover information acquisition, visualization, and processing analysis and whose development is built on easy-to-learn high-level language. Moreover, many of the current powerful software packages are therefore commercial and lack certain third-party functionality extensions. Therefore, this study proposes the hybrid brain-computer interface (HBCI), a new and more flexible Python-based software tool consisting of four main modules: an EEG amplifier, a BCI paradigm, EEG data storage and EEG data analysis. An EEG amplifier compatible with the MindBridge-Nano (developed by Guangzhou Qianga Neuroscience Technology Co., Ltd.) hardware platform was used for real-time data acquisition and processing. The BCI paradigm facilitates the rapid integration of third-party paradigms and BCI experimental stimuli. EEG Data Storage is dedicated to data storage and online/offline visualization, while EEG data analysis provides various methods of data processing and analysis. The software platform in this study has several notable advantages: (i) comprehensive capabilities in terms of data collection, storage, processing, and visualization, effectively addressing the complexity of data processing and reducing the learning curve; (ii) support for data format conversion between CSV, OpenBCI, MNE, and EDF, enhancing the efficiency of EEG data sharing; (iii) leveraging Python and Matplotlib for rapid and high-quality real-time visualization of temporal, spectral, and spatial EEG data, providing users with intuitive feedback; and (iv) providing interfaces for third-party paradigms such as SSVEP, P300, and MI, demonstrating good extensibility. This enables researchers to quickly engage in BCI research analysis and inspires more ideas from the BCI community. The HBCI holds significant promise and significance in scientific research and brain information analysis.

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1 HARDWARE DEVICES

1.1 MindBridge hardware products

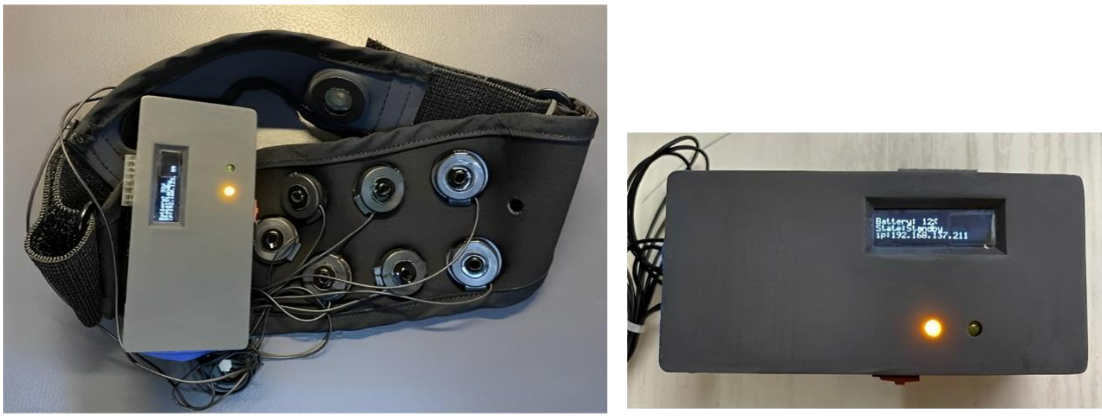
The MindBridge series wireless EEG acquisition platform is an advanced wireless brainwave device independently developed by Guangzhou Qianga Neuroscience Technology Co., Ltd. This platform is characterized by outstanding portability, stable signals, and effective shielding. Individuals can engage in traditional psychology/brain-computer interface (BCI) research within shielded environments or conduct more natural and flexible experiments outdoors. The electrode positions of the MindBridge series follow those of the international 10-20 system and currently offer four configurations: 8, 16, 32, and 64 channels. as shown in **Figure 1** for the 32-channel hardware product. These configurations are suitable for various fields, including brain-machine interfaces, psychology, neuromarketing, and rehabilitation engineering. The signal quality of the MindBridge series is better than that of traditional wired EEG devices, while being more compact and portable and suitable for a variety of scenarios. The EEG caps provided with the MindBridge series amplifiers are three sizes, ensuring a perfect fit for various head shapes while guaranteeing signal quality and comfort during the data collection process.

(A) (B)

Figure 1 (A) MindBride 32-channel product diagram. The product includes an EEG cap accessory, EEG acquisition hardware, and charger accessory. **(B)** Side view of the MindBridge 32-channel EEG cap

1.2 Hardware device overview

MindBridge uses a Wi-Fi connection mode to establish a TCP-long connection for bidirectional data communication with a computer. We conducted embedded development using VSCode+ESP-IDF as the development environment, based on the official Internet of Things (IoT) development framework provided by Espressif (Espressif). On the hardware side, we selected the ADS1299 EEG chip for EEG data acquisition and processing. The ADS1299 is a 24-bit analog-to-digital converter designed by Texas Instruments specifically for bioelectric measurements. In addition, we integrated an ESP32 wireless module to enable wireless transmission of EEG data. Our EEG amplifier offers a maximum sampling rate of up to 2000 Hz (**Figure 2A** shows an 8-channel EEG amplifier in the occipital region) to ensure high-quality acquisition of EEG signals. The screen on MindBridge-NaNo can display information such as the battery level and experimental status (where “Standby” indicates a waiting state, signifying that the hardware is not connected to the host computer software, and “Streaming” indicates that the device is connected to the host computer and actively transmits data) and the hardware device’s IP address in the local network. The screen status is shown in **Figure 2B**. It is worth noting that we paid special attention to the lightweight design of the EEG amplifier to minimize the burden on users during EEG data collection.



(A) (B)

Figure 2 (A) An 8-channel MindBridge-Nano-8 EEG amplifier with electrodes placed in the occipital region**. (B)** The diagram displays the status screen of the device, where the first row indicates the current device battery percentage, the second row shows the device's connection status, and the third row represents the device's IP address on the local network.

Indicator parameters

- The number of EEG signal acquisition channels (16/32/64) can be matched
- Sampling frequency 1000 Hz
- Signal input impedance ≥1 GΩ
- Input signal common mode rejection ratio ≥110 dB
- Signal sampling accuracy 24 bit
- Input noise ≤1.4uVpp
- Input interface: hdmi/pin header interface

- Output mode: Wi-Fi wireless transmission
- System life 12 h, charging time 2 h

2 HBCI SOFTWARE

2.1 Software architecture*:*

On the software side, we adopted Python as the underlying framework because of its advantages in the field of high-level open-source languages. The Python language is characterized by concise and clear syntax, as well as a large ecosystem of third-party libraries. The system utilizes Mne as the third-party library for EEG data processing, sockets for software communication, and Matplotlib for drawing real-time EEG images. Python Excel was used for big data processing, and the NumPy library was used for data processing and conversion. The readability of the Python code, noted for its conciseness, significantly reduces the learning curve and maintenance overhead for our development team. The system uses Python version 3.8.4, which is compatible with mainstream computer and Windows operating systems.

The GUI architecture of this system adopts a hybrid approach, combining the PyQt5 software framework with a web interface to build the user interface. PyQt5 is a cross-platform library that supports writing code once and deploying it on multiple platforms. Additionally, PyQt5 provides a rich component library, offering a diverse range of functionalities for the system. By using the PyQt5 + Web development approach, the user interface is presented in web format, leveraging the flexibility of the web and the advantages of cloud services to make the system more lightweight. The hybrid PyQt5 + Web architecture provides greater flexibility than the other models, enabling rapid development iterations to meet various functional requirements.

2.2 Software functionalities*:*

The main interface of the software is depicted in **Figure 3**. In **Figure 3(A)**, the software's functional navigation bar is illustrated, comprising options for collecting parameter configuration, impedance testing, data processing, file format conversion, and third-party paradigm integration marking. **Figure 3(B)** displays the device information section, with a left-sided list for selecting device models—providing four options: MindBridge-8, MindBridge-16, MindBridge-32, and MindBridge-64, corresponding to four channel configurations. On the right, users can input the IP address of the device on the local network, which will be displayed on the device screen. **Figure 3(C)** provides an overview of the "HBCI Team," and **Figure 3(D)** includes the "Contact Us" section, featuring the team's contact address and website.

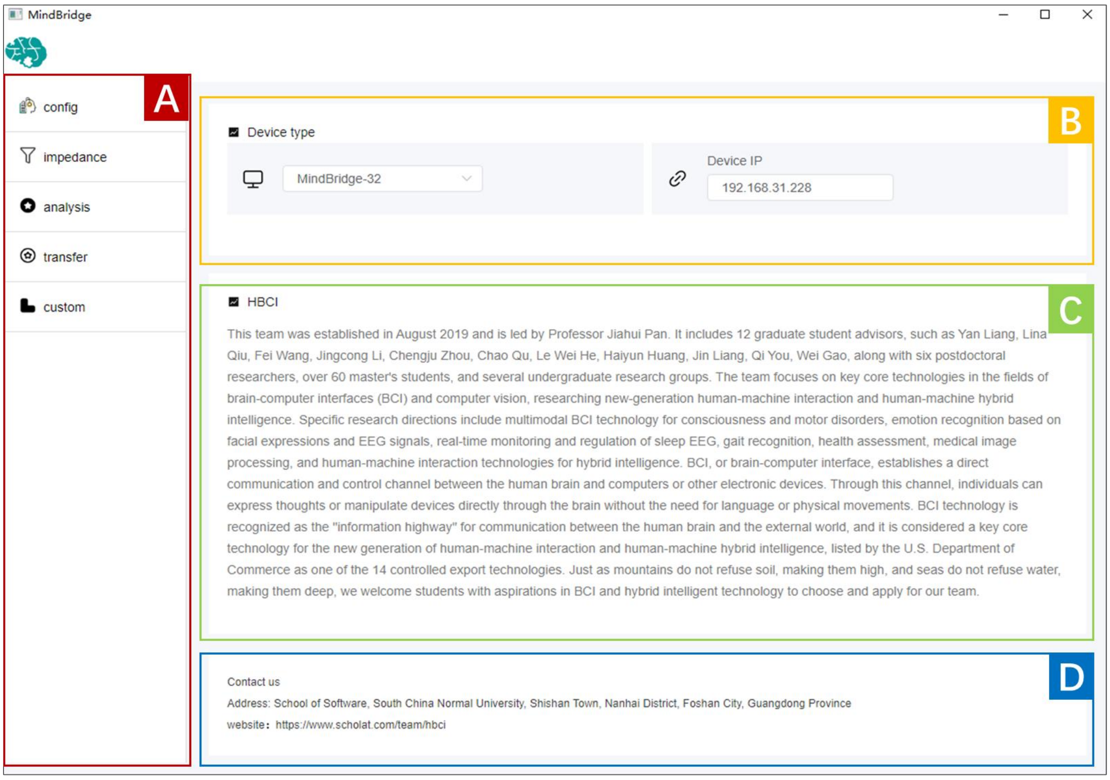


Figure 3. The HBCI Main Interface. **(A)** Software function navigation bar, including options for acquisition parameter configuration, impedance testing, data processing, file format conversion, and third-party paradigm integration for marking. **(B)** Device information section, with a list on the left to select the device model - offering four options: MindBridge-8, MindBridge-16, MindBridge-32, and MindBridge-64, corresponding to the four channel configurations. On the right, the IP address of the device can be input to the local network, which will be displayed on the device's screen. **(C)** Presentation of the HBCI team introduction. **(D)** Contact us. The team's contact address and website were displayed.

2.2.1 EEG amplifier

The EEG Amplifier is a hardware device that communicates with HBCI software via a socket communication mode to transmit real-time EEG data and event marker data. The MindBridge EEG acquisition platform operates with a default sampling frequency of 1000 Hz and utilizes a 24-bit gain amplification factor. MindBridge interacts with HBCI software to transfer real-time EEG data for storage and analysis. Furthermore, it provides real-time graphical visualization of EEG data, processes EEG data based on paradigm markers, and offers offline analysis capabilities.

2.2.2 BCI paradigm integration

The HBCI software utilizes the socket communication method to exchange data and execute commands with third-party software, as shown in **Figure 4**. During the SSVEP, P300 and MI experiments, the system transmits the data to be labeled via sockets, which are embedded in the real-time EEG data stream. This system transfers the data that need to be marked via sockets and embeds them into the real-time EEG data stream. This feature is particularly useful for offline data analysis, allowing for data segment extraction and task data annotation. Upon completion of an experiment, the backend displays detailed information about the labeling process, including prompts regarding successful or unsuccessful data saving, the local address where the data are saved, and the EEG experimental data saved in CSV file format. Additionally, the software's socket communication provides real-time EEG data for use by third-party software for EEG-related processes such as real-time assessment of brain state and algorithmic analysis.

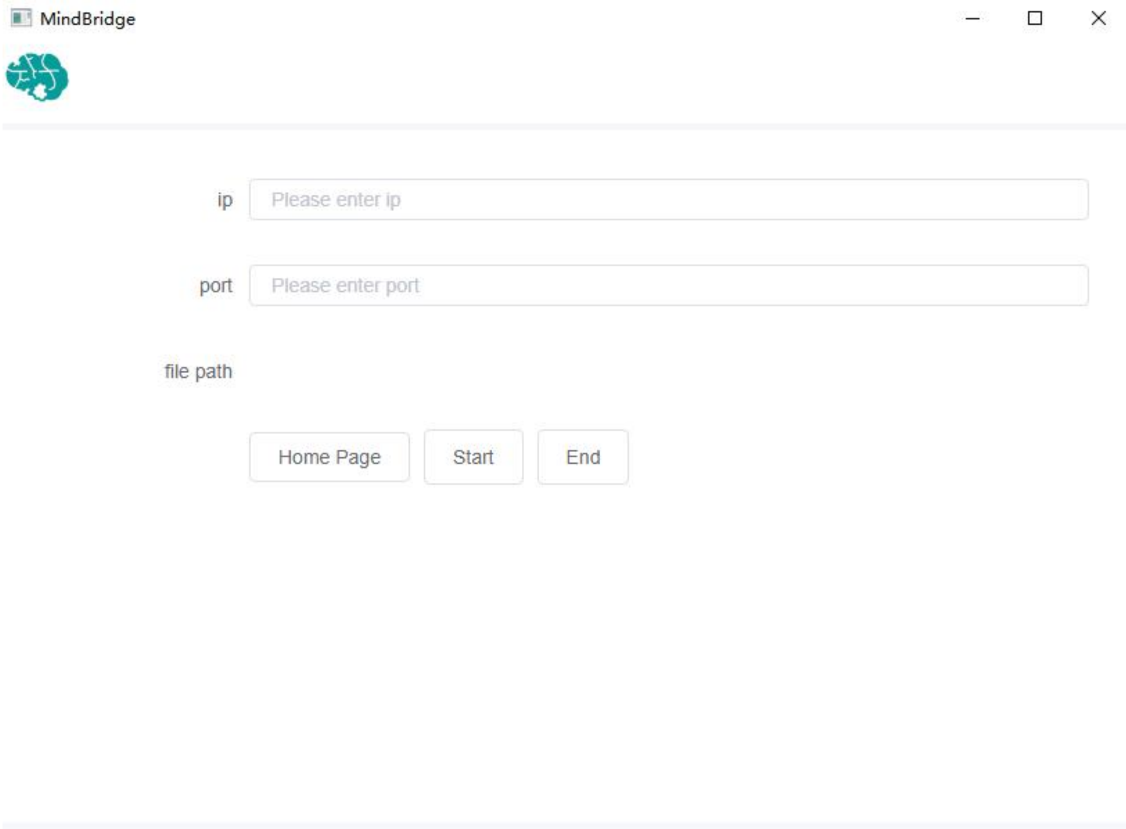


Figure 4 The paradigm integration interface. It allows users to input the IP address and port values. Once the experiment begins, a third-party paradigm program can transmit real-time event markers to the software, which embeds these markers into the EEG data. After the experiment concludes, the data are saved in the form of a CSV file, and the interface displays the storage path.

2.2.3 Impedance check

During EEG experiments, it is necessary to monitor the connection status between EEG electrode devices and the scalp, which is typically represented by impedance values**.** The size of the impedance displayed in the circular channels in the brain area reflects the quality of the connection between the scalp and the electrodes, which in turn affects the quality of EEG signal acquisition. Generally, during EEG experiments, the impedance resistance of the electrodes must be less than 5 KΩ. This impedance detection module, designed in this system, is capable of real-time monitoring of EEG impedance data, as shown in **Figure 5**, to ensure effective electrical conductivity.

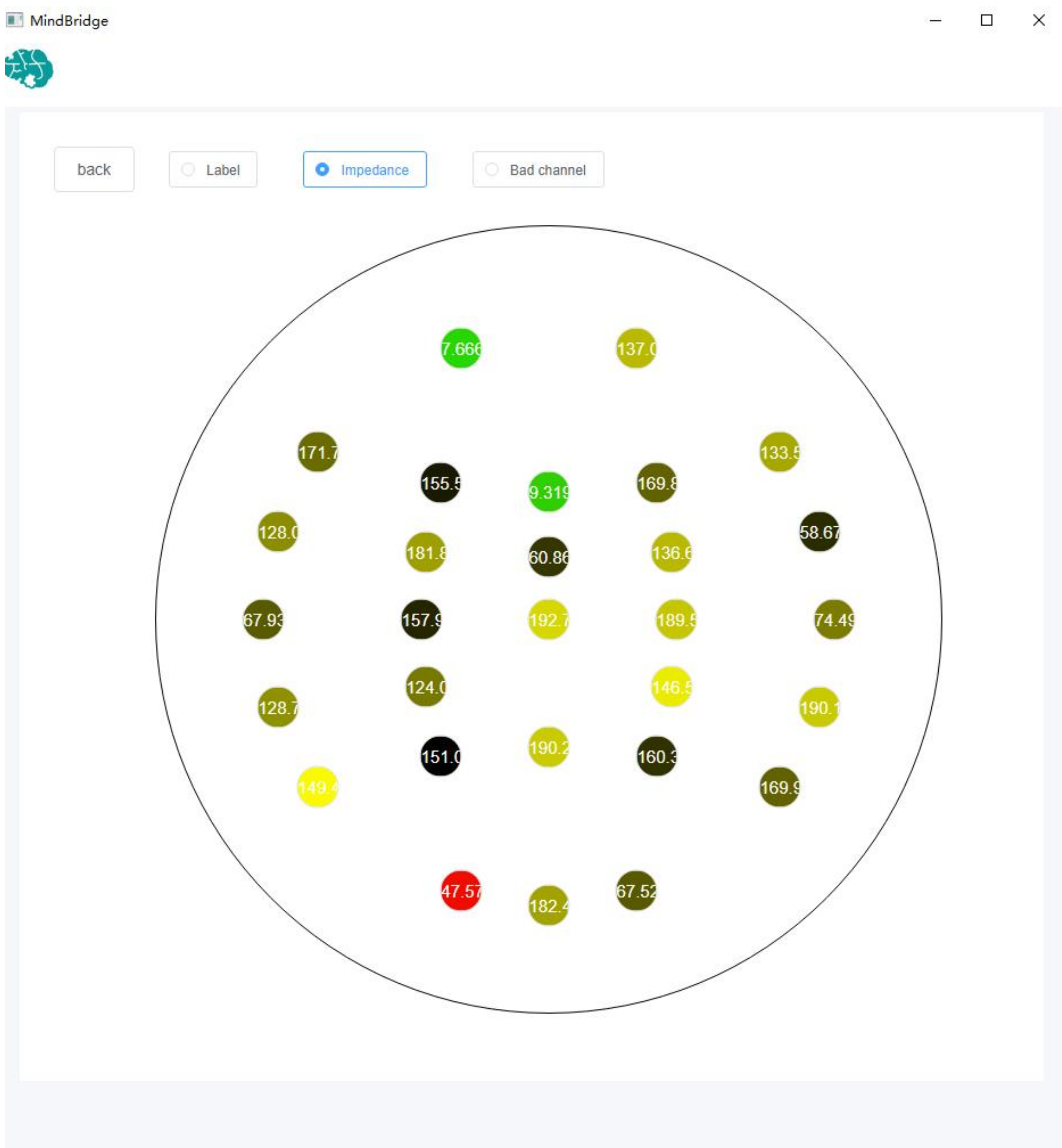


Figure 5 The EEG impedance detection interface. In this interface, each channel is represented by a small circular area displaying the impedance value. A value less than 10 is shown in green, indicating good impedance. If the value exceeds 10, the color gradually darkens as the value increases, signifying higher impedance.

As shown in **Figure 5**, we used the MindBridge-Nano32 amplifier to display 32 channels of EEG impedance data. In **Figure 5**, green indicates good impedance, while red indicates high impedance; colors closer to green indicate smaller impedance values, and colors closer to red indicate higher impedance values. There is a bad conductance marker in the upper left corner of the interface. During EEG experiments, some electrodes may not be able to meet the impedance requirements, and these electrodes can be labeled bad conductors. These bad conductor electrodes will not participate in the data analysis during the offline analysis phase.

2.2.4 Real-time EEG data visualization

In EEG experiments, real-time visualization of EEG data is of utmost importance because it aids in monitoring whether any anomalies occur with the subjects, such as

EEG cap displacement or instrument malfunctions, that may render the data unusable. Real-time image display enables the presentation of EEG waveforms and associated real-time features, as illustrated in **Figure 6**.

Figure 6 shows the visualization interface for real-time EEG data, which includes three images: a waveform map, a spectrogram and a topographic map of the brain area. The data are presented at a sampling frequency of 1000 Hz, and each channel has a corresponding label on the left waveform graph. This helps to correlate the data with the individual channels. The upper right spectrogram shows the data after fast Fourier transform (FFT) processing, where the signal data are divided into different frequency components. This visualization helps to determine in which frequency ranges there is a significant EEG response, which in turn helps to identify the frequency ranges relevant to the EEG task.

The bottom right corner of the interface shows a topographical map of the EEG, with different electrodes corresponding to different brain regions. The color shading in the topographic map reflects the variation in different EEG intensities. Areas with colors closer to red indicate weaker EEG changes, while colors closer to blue indicate stronger brain activity. The visualization interface intuitively shows the activity of different brain regions and can provide important visual information.

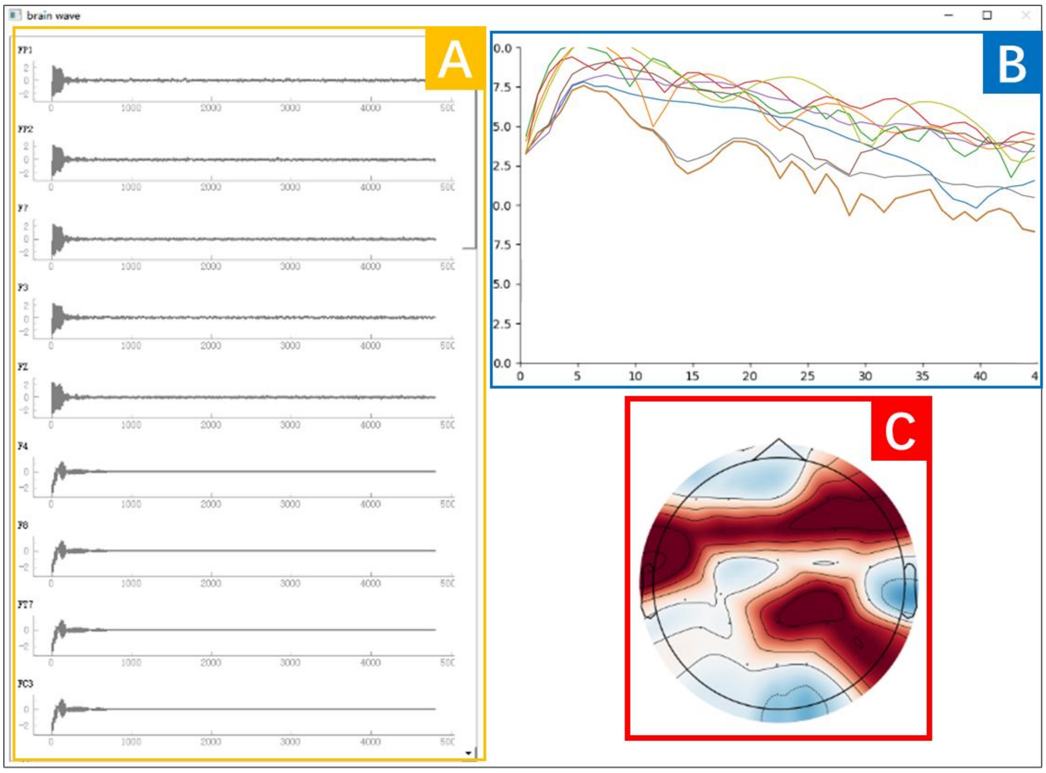


Figure 6 Real-time EEG visualization interface. **(A)** Five-second time window of real-time EEG data, currently displaying only channels (FP1, FP2, F7, F3, FZ, F4, F8, FT7, and FC4). **(B)** The spectrogram displays frequency–amplitude representations of all the recorded channels. **(C)** Topographic data representation.

2.2.5 File format conversion

Our system primarily stores real-time EEG signals in CSV data format by default. Within the software, users have the flexibility to convert these data into TXT files, which is compatible with OpenBCI. Additionally, the software offers support for transforming data into the EDF format, allowing for viewing in EDFBrowser, as depicted in **Figure 7**. Furthermore, our software facilitates the import of data into EEGLAB for advanced data processing and analysis. Additionally, the user has the option to insert experimental information into the generated file by providing operator details, subject name, subject ID, additional subject information, subject age, and selecting the subject's birthdate.

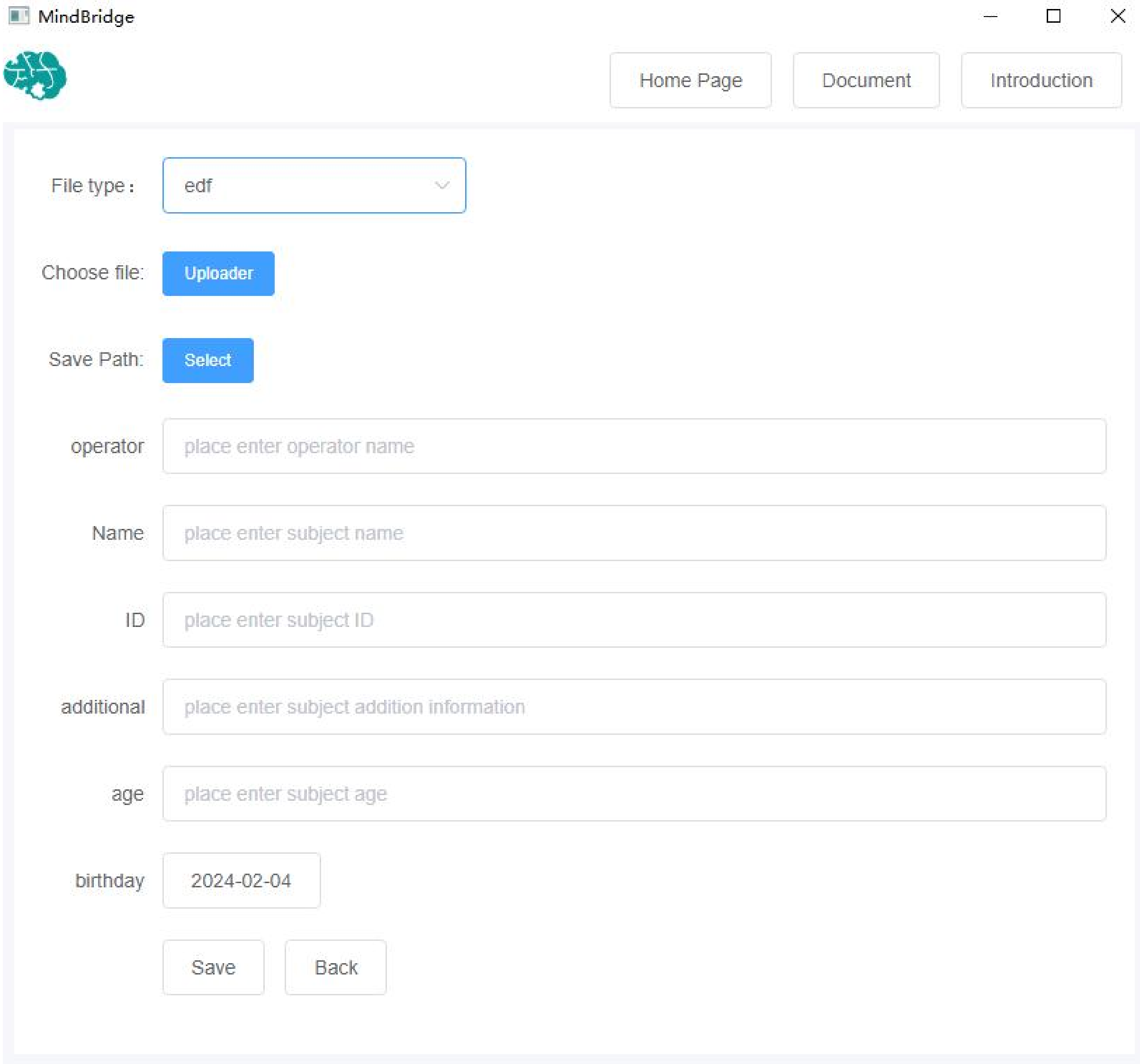


Figure 7 File Format Conversion Interface: This interface offers support for converting data into three different file formats: OpenBCI data conversion, MNE data conversion, and EDF data conversion. The file is simply selected, the save path is specified, and the "Generate File" is clicked to perform the data format conversion. Additionally, the user has the option to insert experimental information into the generated file by providing operator details, subject name, subject ID, additional subject information, subject age, and selecting the

subject's birthdate.

2.2.6 Data analysis

The HBCI provides a series of basic preprocessing and preset correlation feature methods. As shown in **Figure 8**, HBCI software is equipped with b baseline drift correction, denoising, filtering, bad lead removal, referencing, segmentation, sample baseline correction, sample segmentation, ample filtering downsampling and other related functions.

- Baseline drift correction: Users can choose whether to perform baseline drift correction. The software used the average baseline method for baseline drift correction.
- Filtering: The software uses bandpass filtering to set low-frequency and high-frequency metrics for signal filtering processing according to user requirements.
- Bad Lead Removal: Circles representing the channel names and positions are generated to simulate the head. Users can click to select any number of channels as bad leads (selected channels are displayed in red; unselected channels, in green).
- Rereferencing: Similar to the bad lead step, this step allows users to select single, multiple, or all electrodes for averaging as a reference point for EEG signal rereferencing.
- Segmentation: The software supports the segmentation of entire data segments based on time units or segmentation based on markers.
- Sample Baseline Correction: Users can customize the number of slices based on marked data and select start and end times. Additionally, users can choose between two sample baselines: average and selected time. If the time-based sample baseline is chosen, users can customize the time from a specific marker as the baseline.
- Sample segmentation: Users can segment data based on sample requirements.
- Downsampling: Users can customize the downsampling of EEG signals to reduce the complexity of the data.
- After adjusting the preprocessing parameters, the feature extraction module provides six feature extraction options, including feature waves, statistical features, PSD features, differential value features, spatial patterns, and feature bands. Users can choose one or more feature extraction methods and adjust the low-frequency and high-frequency thresholds for feature waves. The custom storage locations can also be defined.
- The selected operation steps generate Python scripts for users to perform custom data processing. Furthermore, the original EEG data are saved in the MAT data format, while the processed data are stored in filtered form.

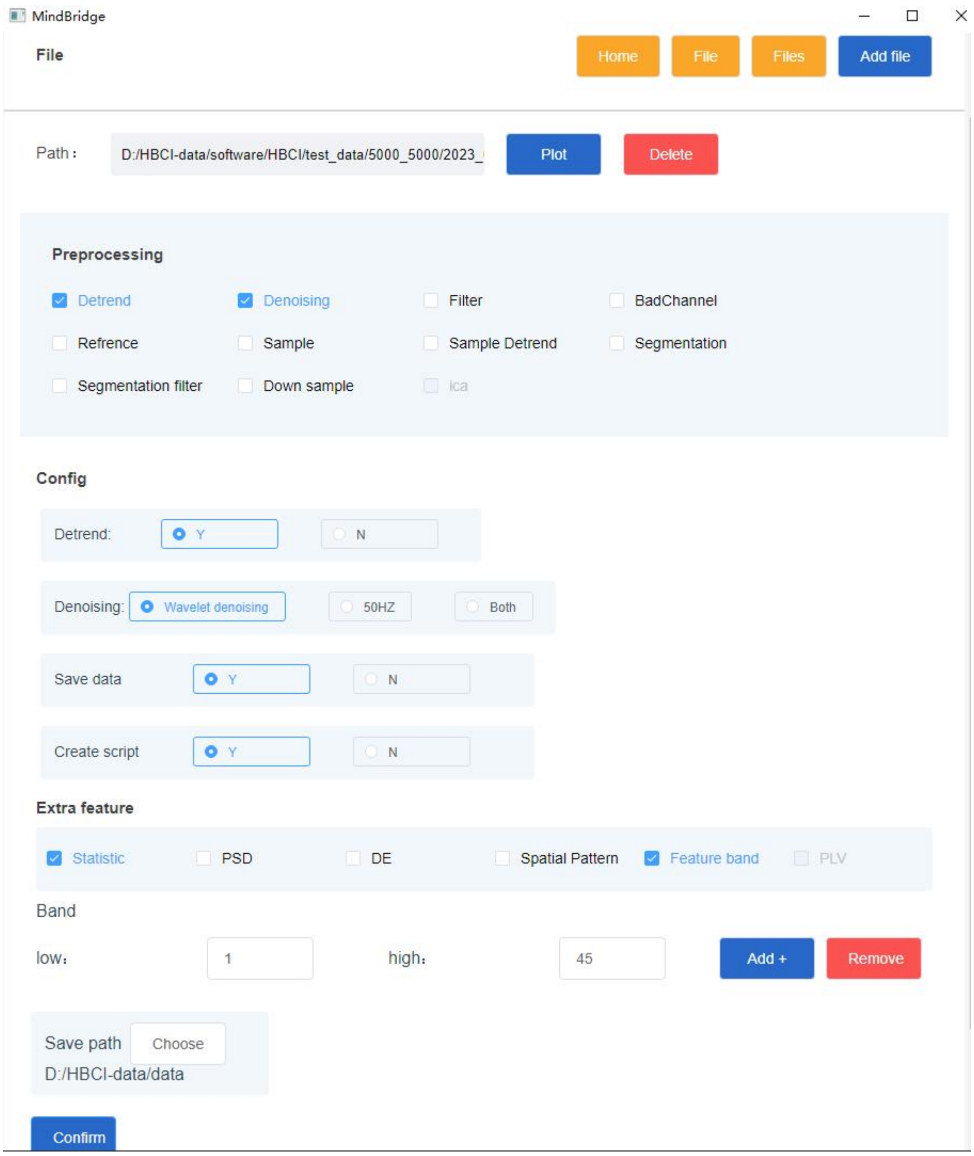


Figure 8 Data analysis interface. This interface offers various preprocessing options. After a file or folder is selected by clicking "Add File," the address bar displays the local path. The interface is divided into two sections. In the preprocessing section, the software provides ten preprocessing steps: baseline drift correction, noise removal, basic filtering, bad channel removal, rereferencing, segmentation, baseline correction, sample segmentation, sample filtering, and downsampling. After one or more steps are selected, the parameter selection section below provides the parameters for the selected steps. Before setting specific parameters, users can choose whether to save data formats and whether to create a script.

3 PRECAUTIONS

3.1 EEG cap instructions for use:

1. The user wears the EEG cap and adjusts the electrode position;
2. The conductive paste is injected into the electrode, and the injection point can be felt until it is cooled;
3. The data transmission interface is connected to the working state of the EEG amplifier;
4. After the first three steps, the real-time EEG waveform can be observed on the monitor (or determined by observing the impedance); if a channel EEG waveform has obvious abnormalities, the first two steps can be repeated for a particular electrode.

3.2 EEG cap precautions:

1. The connector (with a metal guide wire) cannot be immersed in water and cannot be dampened;
2. Do not use needles or hard materials to scrape the surface of the electrode cap;
3. Avoid direct sunlight;
4. The use of disinfectants containing oxidizing or reducing agents (such as hydrogen peroxide, potassium permanganate solution, iodine, Neosporin, Pasteur disinfectant, or bleach) should be strictly prohibited; otherwise, the performance of the electrode should be affected.

3.3 Precautions for EEG amplifier:

1. The device should be used when the power is sufficient, and use should be avoided when charging.
2. Please use it after testing the amplifier working normally.
3. Please connect the corresponding lead electrodes of each channel correctly, try not to connect the wrong one.
4. The interference sources, such as a 220 V AC power supply, a switching power supply, large instruments or strong interference sources, should be avoided.