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Information Technology — Brain-computer Interfaces — Use Cases

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INFORMATION TECHNOLOGY – BRAIN-COMPUTER INTERFACES – USE CASES

FOREWORD

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The text of this Technical Report is based on the following documents:

Draft	Report on voting
JTC1-SC43/134/DTR	JTC1-SC43/152/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1, and the ISO/IEC Directives, JTC 1 Supplement available at www.iec.ch/members_experts/refdocs and www.iso.org/directives.

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INTRODUCTION

Brain-computer interface (BCI) has unique technical aspects, and there are few similar international standards or technical reports.

This document provides a collection of representative use cases of brain-computer interface applications in a variety of domains. The current document reflects contributions and discussions by ISO/IEC JTC 1/SC 43 experts and liaison members.

In particular, SC 43 performed research on the standardization requirements of BCI, and this document presents the conclusions. BCI technology is gradually being applied to many real-world application fields, including smart environments, medical and health, education, industrial control, and gaming. In the future, this technology will bring new changes and developments in more fields. Therefore, to ensure that BCI technology can better benefit humans, it is important to carry out standardization research work on the technology, which mainly focuses on the standardization of BCI technology, ethics, and safety.

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INFORMATION TECHNOLOGY – BRAIN-COMPUTER INTERFACES – USE CASES

1 Scope

This document provides a collection of representative use cases of brain-computer interface (BCI) applications in a variety of domains: proposed medical and health, industrial controls, smart environment, etc.

This document can be used for the development of potential standards, and it is valuable for a better comprehension of BCI.

This document is also helpful for BCI industries and products that provide support for communications among interested parties and stakeholders.

This document is applicable to all types of organizations (e.g. commercial enterprises, government agencies, not-for-profit organizations).

2 Normative references

ISO/IEC 8663, *Information technology – Brain-computer interfaces – Vocabulary*[1]

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 8663 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
minimally invasive BCI
minutely invasive BCI
invasive brain-computer interface paradigm or system which requires a surgical procedure but with a low risk of infection and a minimal contact or disruption of neural tissue and vasculature

Note 1 to entry: The electrodes can be placed outside the dura mater (epidural).

3.2
implanted sensor
implantable sensor
sensor which is placed inside the body after surgical incisions, providing accurate in vivo physiological measurement in humans and other animals

[1] Under preparation. Stage at the time of publication: ISO/IEC CDV 8663:2024.

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3.3
classifier
trained model and its associated mechanism used to perform classification

[SOURCE: ISO/IEC TS 4213:2022, 3.1.2]

3.4
target stimulus
stimulus to which subjects in a test or procedure must respond

Note 1 to entry: Among many stimuli, a person selects the one to which he or she responds.

Note 2 to entry: Adapted from reference [1].

3.5
external stimulus
stimulus that originates from outside the organism and that does not rely on the subject's reaction

Note 1 to entry: External stimulus can be an electrical, optical, auditory or mechanical signal, cue or event.

3.6
motion-onset visual evoked potential
mVEP
neural potential that occurs when motion-related stimuli are attended visually

Note 1 to entry: Adapted from reference [2].

3.7
deep brain stimulation
DBS
neurosurgical technique that uses implanted electrodes and electrical stimulation to treat neural disorders

Note 1 to entry: Deep brain stimulation is the most performed surgical treatment for Parkinson's disease.

3.8
functional electrical stimulation
FES
activity-based intervention that extrinsically activates the neuromuscular system below the level of the lesion, inducing plasticity of the neuromuscular and central nervous systems

3.9
mental state
mental property
mental condition
set of characteristics of a person's affective and psychological mode or status

3.10
vegetative state
clinical condition of complete unawareness of the self and the environment, accompanied by sleep–wake cycles, with either complete or partial preservation of hypothalamic and brainstem autonomic functions

Note 1 to entry: Adapted from reference [3].

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3.11
minimally conscious state
clinical condition of severely altered consciousness in which minimal but definite behavioural evidence of self or environmental awareness is demonstrated

Note 1 to entry: This definition is taken from reference [4].

3.12
awareness detection
method to explore and measure the quality or state of the subject's consciousness

Note 1 to entry: Usually, awareness detection is performed by evaluating vegetative state and minimally conscious state.

3.13
biometrics system
system that enables a person to be identified and authenticated through capturing the recognizable, verifiable, unique, and specific physiological data

3.14
cursor control
brain-computer interface system that presents a user with a movable item used to mark a position and translates the moving direction by interpreting the user's neural activities

3.15
shared control
<system> characterized by the use of both user control and an automation component

Note 1 to entry: A shared control BCI system uses both the direct input from the user by interpreting neural activities and assistance from artificial intelligence technology.

3.16
online analysis
type of brain-computer interface (BCI) classification procedure that is performed immediately following data acquisition, translating neural activities into BCI commands

Note 1 to entry: Online analysis must be used in real-time BCI applications.

3.17
offline analysis
offline training
type of brain-computer interface classification or training procedure performed at a separate time after data acquisition is completed

3.18
classification accuracy
metric for evaluating classification models in brain-computer interface prediction

Note 1 to entry: Accuracy equals the number of correct predictions over the total number of actual predictions.

3.19
information transfer rate
ITR
evaluation metric devised for brain-computer interface systems that determines the amount of information that is conveyed by a system's output per unit time

Note 1 to entry: Adapted from references [5] and [6].

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4 Abbreviated terms

ANN	artificial neural network
AR	augmented reality
BCI	brain-computer interface
BMI	brain-machine interface
CRS-R	coma recovery scale – revised
CSP	common spatial pattern
CT	computed tomography
DBS	deep brain stimulation
DOC	disorders of consciousness
ECoG	electrocorticogram
EEG	electroencephalography
EER	equal error rate
EMG	electromyogram
EOG	electro-oculogram
FBCCA	filter bank canonical correlation analysis
FDA	Food and Drug Administration
FES	functional electrical stimulation
FPGA	field-programmable gate array
fMRI	functional magnetic resonance imaging
fNIRS	functional near-infrared spectroscopy
iEEG	intracranial electroencephalography
I/O	input or output
ITR	information transfer rate
LFP	local field potential
LiDAR	light detection and ranging
MI	motor imagery
MRI	magnetic resonance imaging
mVEP	motion-onset visual evoked potential
NIRS	near-infrared spectroscopy
PCA	principal components analysis
RAA	reading assessment apparatus
SEEG	stereoelectroencephalography
SoC	system on chip
SSVEP	steady-state visual evoked potential
VR	virtual reality

5 Data analysis of BCI use cases

5.1 List of use cases

Table 1 shows summary information for each of the 32 use cases, including name, application domain, and status. Subclauses 7.3 to 7.8 provide details on each use case, listed by application domain.

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Table 1 – List of use cases

No.	Title	Application domain	Status
1	Passive brain-computer interface (pBCI)-based adaptive automation (AA)	Smart environment	Proof of concept
2	BCI-based smart ward system	Smart environment	In operation
3	Brain-machine interface (BMI) enabled assistive communication system	Smart environment	Proof of concept
4	Monitoring and early warning technology for the fitness of special operations personnel based on EEG signals	Smart environment	In operation
5	Minimally invasive implanted closed-loop brain-computer interface system	Medical and health	Proof of concept
6	Neural state dependent closed-loop deep brain stimulation	Medical and health	In operation
7	Invasive brain cursor control system	Medical and health	Proof of concept
8	Multi-site closed-loop neurostimulation for clinical seizure modulation	Medical and health	Prototype
9	AR-based brain-computer interface for upper limb rehabilitation	Medical and health	In operation
10	Brain-controlled robot grabbing to assist daily life	Medical and health	In operation
11	Rehabilitation training system based on MI-BCI	Medical and health	In operation
12	Brain-computer interface in diagnosis and treatment of depression	Medical and health	In operation
13	The M-score: motor function assessment using BCI	Medical and health	Proof of concept
14	Shen Gong robotics: BCI-driven rehabilitation training system	Medical and health	Proof of concept
15	Music intervention based on brain-computer interface system	Medical and health	Prototype
16	Wearable seizure onset detection system	Medical and health	Proof of concept
17	Clinical diagnosis and prognosis in patients with disorders of consciousness (DOC)	Medical and health	In operation
18	An adaptive AR display to improve situational awareness using BCI in stressful and fatigue-inducing situations	Medical and health	In operation
19	Portable brain-related symptom screening, monitoring and surveillance system using non-invasive electroencephalograph	Medical and health	In operation
20	Portable brain-related symptom management system using non-invasive brain stimulation	Medical and health	In operation
21	Automated seizure detection and prediction	Medical and health	Proof of concept
22	Near-infrared BCI intervention in patients with stroke	Medical and health	Proof of concept
23	Fusion of multi-modal fNIRs and EEG information for motor imagery classification	Medical and health	Proof of concept
24	BCI controlled exoskeleton with seven degrees of freedom for assistance and rehabilitation applications	Medical and health	Proof of concept
25	BCI controlled wheelchair for assistance and rehabilitation	Medical and health	Proof of concept
26	Reading assessment apparatus (RAA)	Learning, education and training	Proof of concept
27	BCI-based biofeedback for accelerated learning	Learning, education and training	In operation
28	Brain-computer interface in aerospace applications	Industrial controls	In operation
29	T-Drone	Industrial controls	In operation

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No.	Title	Application domain	Status
30	Cognitive regulation based on brain-computer interface game	Gaming	Prototype
31	The MindGomoku: an online P300 BCI game	Gaming	Prototype
32	Non-invasive brain signal-based biometrics system	Security and authentication	Proof of concept

5.2 Application domains

Figure 1 describes the distribution of use cases by application domain. Six application domains – security and authentication, smart environment, medical and health, learning, education and training, industrial controls, and gaming – were considered as target domains for the use cases.

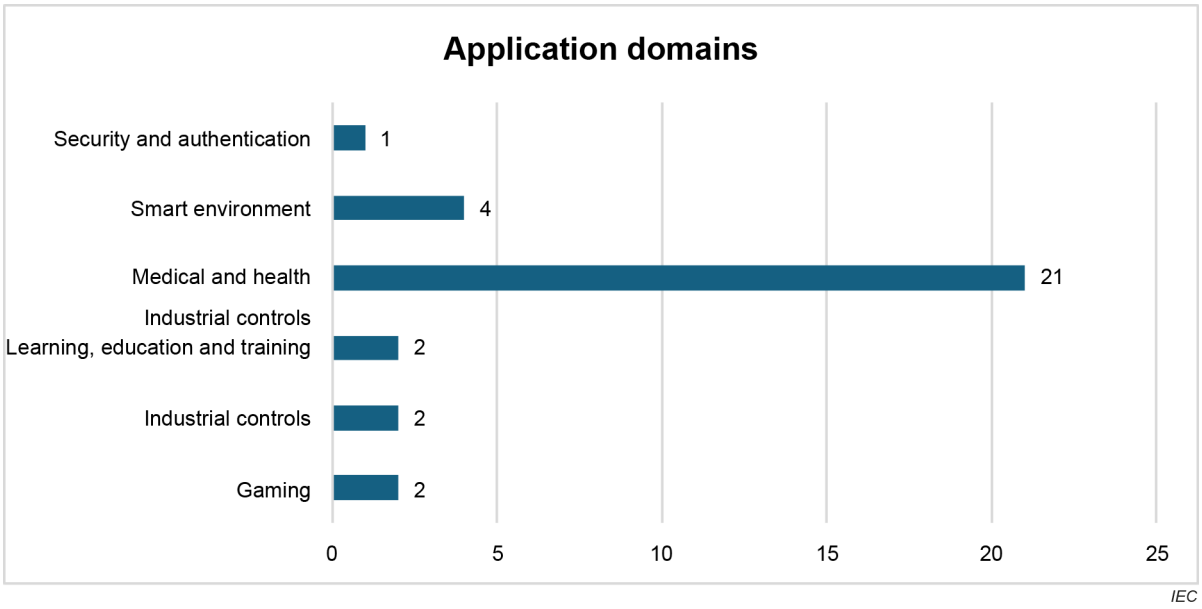


Figure 1 – Application domains of all the collected BCI use cases

5.3 Data characteristics and processing methods

5.3.1 General

BCI mainly identifies users' intentions by analysing the acquired brain electrical signals. There are two main methods for collecting brain electrical signals: invasive and non-invasive. The advantage of invasive methods is that the accuracy of electrical signals is high, but this method has certain surgical risks. Relatively speaking, non-invasive methods are more convenient and safer.

5.3.2 The characteristics of EEG

Electroencephalography (EEG) signals, as a kind of bioelectrical signal, directly reflect the simplest brain activity. Compared with other physiological electrical signals, EEG signals have the following five characteristics.

a) They are very weak, measured in microvolts (μV), with frequencies ranging from 0,5 Hz to 100 Hz. EEG signals are easily contaminated with noise, such as power-line interference, electro-oculogram (EOG), and electromyogram (EMG).

b) The EEG signals exhibit strong randomness and instability, which means that the statistical characteristics of the EEG are independent of time.

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c) They are nonlinear because the relationship between the EEG signals and time does not satisfy a linear function.

d) EEG signals have prominent frequency domain features. Specifically, they have relatively stable frequency components. Different EEG frequency components have different contributions to different brain activity states.

e) The EEG signals are coupled, meaning that different channels of EEG signals have a strong interrelationship.

5.3.3 EEG signal processing methods

Because of these characteristics of EEG signals, they face great challenges in data processing. The signal processing of BCI systems mainly includes four parts: pre-processing, feature extraction, feature selection, and classification. First, the original EEG acquired is denoised by pre-processing. Pre-processing aims to improve the quality of the brain signal and to highlight the signal features. For EEG-based BCI system, pre-processing standardization terms include referencing, ocular artifact removal, time or frequency or spatial-domain filtering, dimensionality reduction, etc. For fMRI-based BCI, pre-processing standardization terms include slice timing, motion correction, spatial normalization, smoothing, filtering, covariance regression and so on. Then, feature extraction means extracting specific features from brain signals that correspond to the users' neurological states. Classical brain signal features include temporal features (e.g. phase locking value), frequency features (e.g. power spectral density), spatial features (e.g. common spatial pattern), etc. Moreover, some feature selection methods, such as principal components analysis (PCA), are often used to resolve the "curse of dimensionality". Machine learning and deep learning algorithms are used to extract data features. Finally, the extracted features are classified and translated into commands for external devices. It is important that classification algorithms are evaluated to ensure their accuracy and reliability.

5.4 BCI common challenges and issues

5.4.1 General

The common challenges among all 32 use cases are summarized in Figure 2.

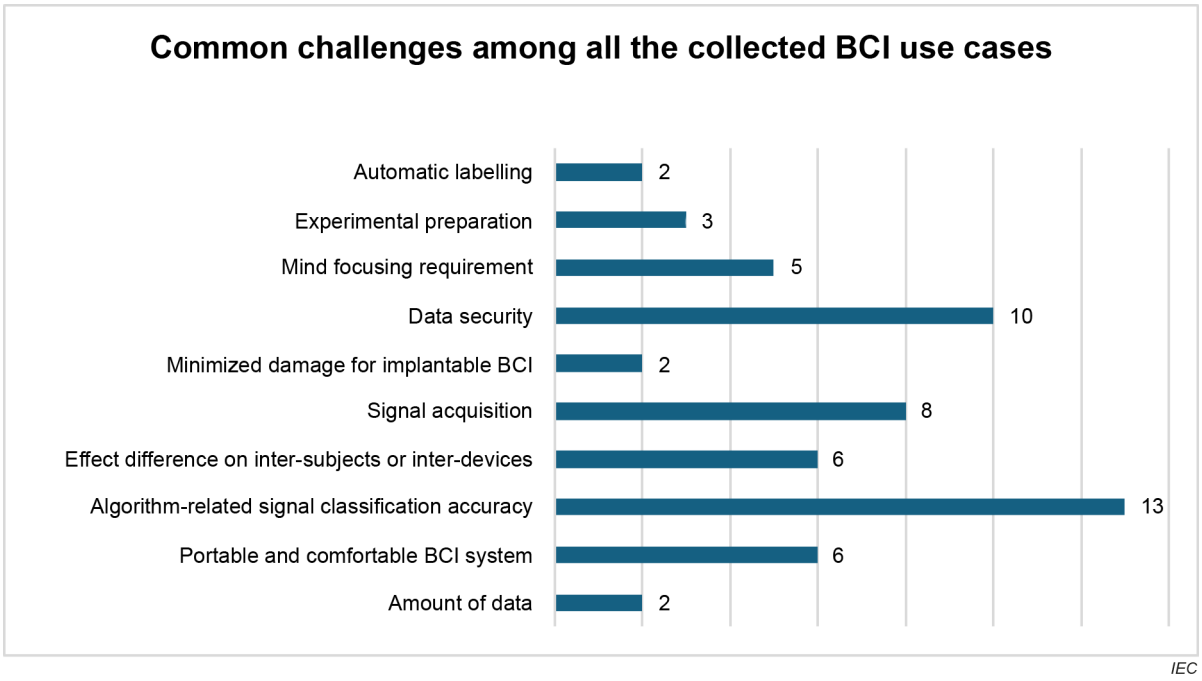


Figure 2 – Common challenges among BCI use cases

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5.4.2 Automatic labelling

Use cases 26 and 29 claim that the method is needed to automatically label and store video feeds and tie to each session for reading assessment apparatus and T-Drone.

5.4.3 Experimental preparation

Use cases 13, 14 and 31 which focused on BCI-based motor function assessment, BCI-driven Shen Gong robotics and the MindGomoku (an online P300 BCI game) seek a shorter procedure of the experiment preparation.

5.4.4 Mind focusing requirement

Use cases 7, 9, 10, 18 and 29 ask for a focusing status, as stray thoughts can affect the system during BCI experiments.

5.4.5 Data security

Use cases 5, 6, 7, 9, 11, 24, 26, 27, 29 and 32 emphasize the importance of data security, especially for privacy concerns and the prevention of data or command changes by hackers.

5.4.6 Minimized damage for implantable BCI

Use cases 5 and 7 aimed at implantable BCI applications raise concerns for minimized damage during scalp surgery. Minimally invasive surgical methods and devices are needed.

5.4.7 Signal acquisition (noise, interference, etc.)

Use cases 4, 5, 8, 11, 16, 18, 27 and 32 propose the challenge of EEG signal acquisition, which is related to the hardware design for low noise, interference resilience, etc.

5.4.8 Effect difference on inter-subjects or inter-devices

Use cases 11, 17, 19, 24, 25 and 32 focus on clinical diagnosis and rehabilitation training, respectively. The effect difference on inter-subjects or inter-devices is challenging when designing such systems in these six use cases.

5.4.9 Algorithm-related signal classification accuracy

The most common challenge among all use cases is the algorithm-related signal classification accuracy. The use cases 1, 2, 4, 8, 11, 15, 16, 17, 21, 23, 27, 30 and 31 demand an improved classification accuracy of the proposed algorithm in BCI experiments.

5.4.10 Portable and comfortable BCI system

Use cases 1, 3, 10, 15, 21 and 30 require a higher level of system integration to improve the portability and reduce the cost for the BCI system.

5.4.11 Amount of data

It is important that more datasets are used to consolidate results in use cases 22 and 23. It is important that the amount of data is expanded in BCI experiments.

5.5 Types, setup, benefits and portability

5.5.1 Invasive or non-invasive

BCI applications can be generally categorized into two main types: invasive BCIs and non-invasive BCIs. As shown in Figure 3, in the 32 use cases presented in this document, 12,5 % were invasive and 87,5 % were non-invasive.

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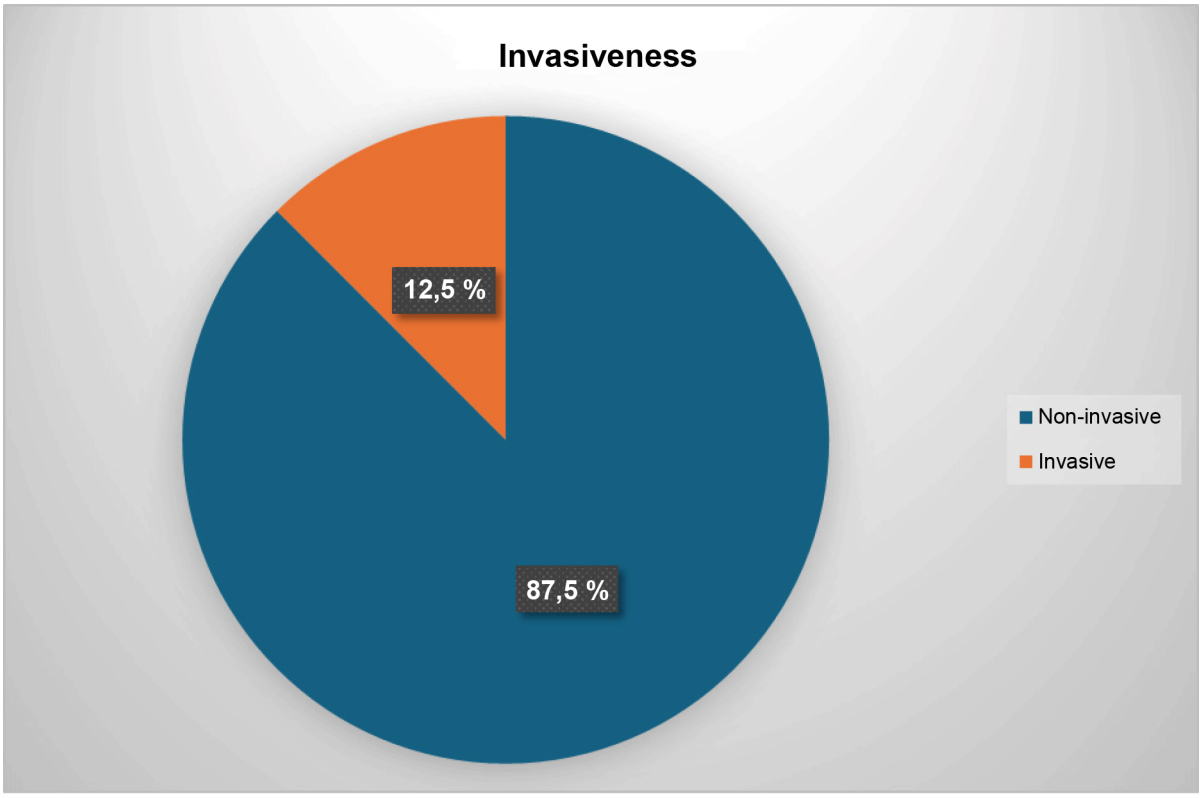


Figure 3 – Invasiveness of all the collected BCI use cases

5.5.2 Required acquisition setup

Highly correlated with the invasiveness of the use case, invasive BCI use cases require surgery to implant electrodes inside the users' skull, and non-invasive BCI use cases usually require cap-like EEG acquisition setups. However, the EEG acquisition technologies can differ in the use cases. For example, in use case 11, a dry EEG acquisition device was used. In use case 19, EMOTIV was used, which is a saline-based EEG acquisition device.

5.5.3 Benefits

The distribution of use cases by benefit is shown in Figure 4. The benefits of BCI use cases are generally reflected in five domains: replacement of the neural pathway, augmentation, diagnosis, restoration, and supplementation. For replacement of neural pathways, BCIs are introduced to create direct communication between the user and external devices. Six use cases fall in this category. For user ability augmentation, two BCI use cases fall in this category, which use BCI in aerospace missions in China for augmentation of astronauts' motor ability and achieve a BCI-based adaptive learning system that accelerated the learning of complex tasks. For the diagnosis of certain conditions and diseases, BCI focuses on brain-related conditions – consciousness, depression, brain injury level, mental load, etc. – and eleven use cases belong to this category. For restoration of users' ability, BCIs are introduced to translate brain activities to commands of external devices to restore part of the users' ability. Ten use cases fall in this category, which is almost one third the number of the total proposed use cases. Finally, to supplement healthy user ability, BCIs can also be used to monitor user ability and provide support accordingly. Three user cases fall in this category.

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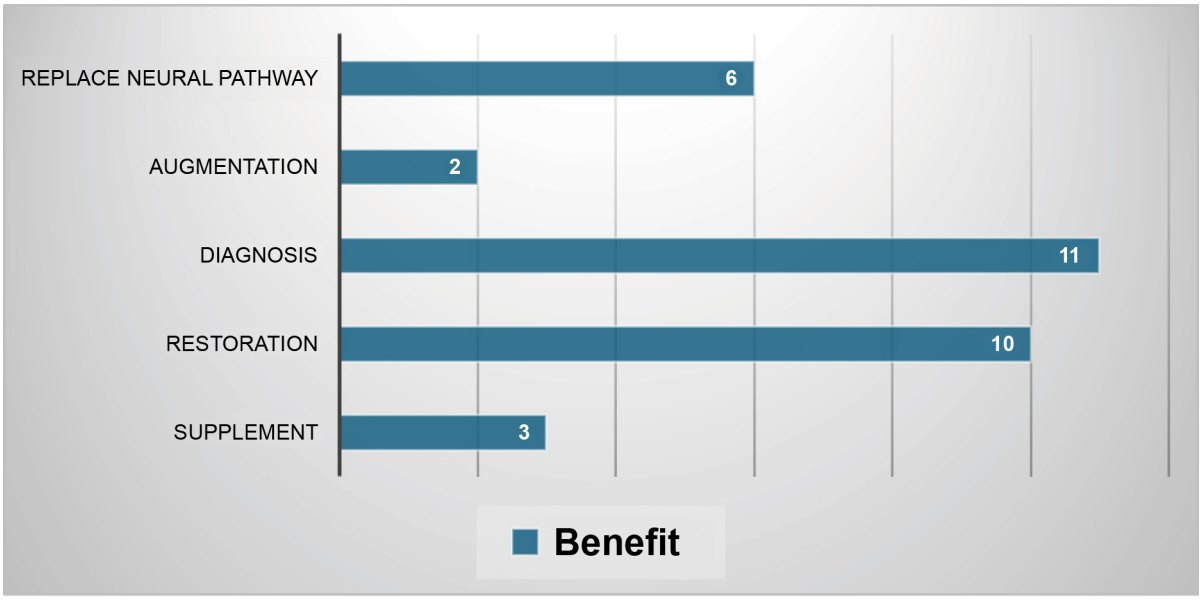


Figure 4 – Benefit of the BCI use cases

5.5.4 Portability

Figure 5 describes the percentage of use cases by portability. In the proposed user case, 81,3 % (26 cases) use a portable system setup, and 18,7 % (six cases) use a stationary system setup.

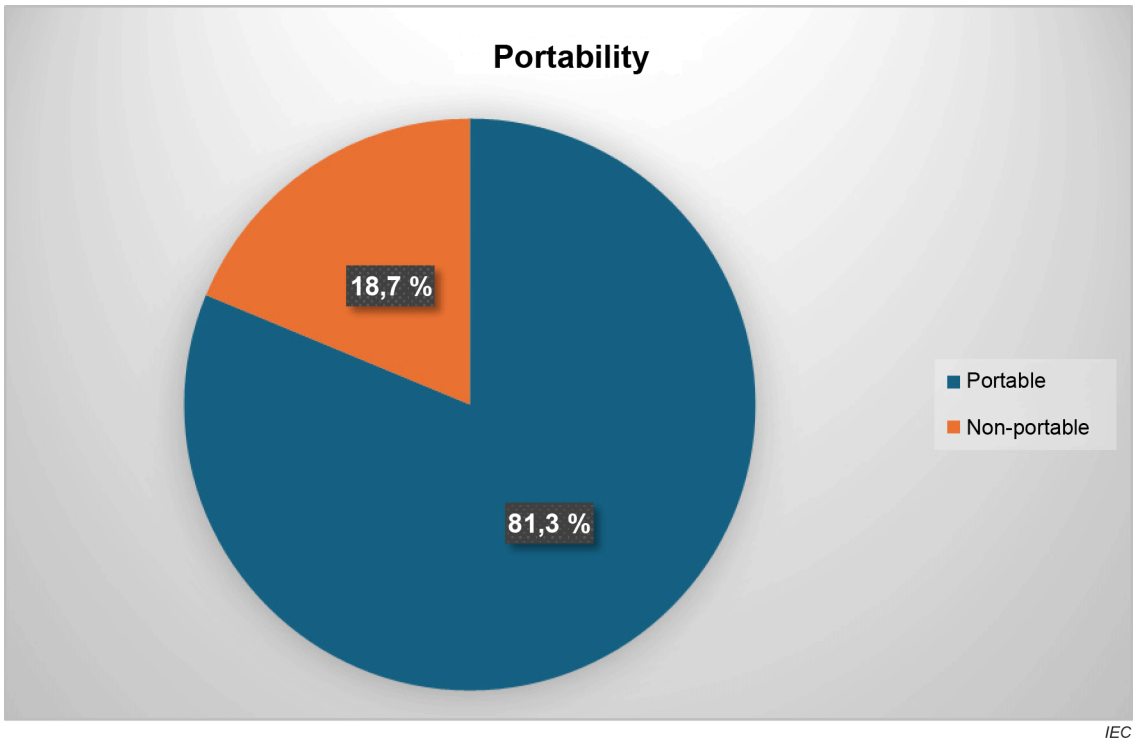


Figure 5 – Portability of the use cases

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6 Standardization requirements

6.1 Summary of standardization requirements of collected BCI use cases

The potential standardization requirements of all the collected BCI use cases are summarized in Table 2.

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Table 2 – The list of standardization requirements from all the collected BCI use cases

No.	Title	Standardization requirements																
		BCI ethics	Security	Signal pre-processing method	Brain signals acquisition	High performance	Trustworthiness	Analytics of BCI data	Registries	Participant identifiers	Model generation method	Intervention	Decoding Algorithm	Biometric systems	BCI experimental paradigm	Data management	Metadata format	Others
1	Passive brain-computer interface (pBCI)-based adaptive automation (AA)			o	o						o							Adaptive strategies
2	BCI-based smart ward system	o	o					o		o			o					BCI smart home
3	Brain-machine interface (BMI) enabled assistive communication system			o	o								o					EEG cap design, software, conversion of EEG or EOG into speech
4	Monitoring and early warning technology for the fitness of special operations personnel based on EEG signals		o	o	o							o	o					
5	Minimally invasive implanted closed-loop brain-computer interface system	o	o				o									o		
6	Neural state dependent closed-loop deep brain stimulation	o	o					o					o					FDA approval
7	Invasive brain cursor control system	o	o			o	o	o	o	o				o		o	o	
8	Multi-site closed-loop neurostimulation for clinical seizure modulation	o	o		o	o	o	o	o	o		o		o		o	o	
9	AR-based brain-computer interface	o					o	o		o						o	o	TCP/IP communication for BCI
10	Brain-controlled robot grabbing to assist daily life	o					o	o						o		o		
11	Rehabilitation training system based on MI-BCI	o	o				o		o									
12	Brain-computer interface in diagnosis and treatment of depression			o		o									o			

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No.	Title	Standardization requirements																
		BCI ethics	Security	Signal pre-processing method	Brain signals acquisition	High performance	Trustworthiness	Analytics of BCI data	Registries	Participant identifiers	Model generation method	Intervention	Decoding Algorithm	Biometric systems	BCI experimental paradigm	Data management	Metadata format	Others
13	The M-score: motor function assessment using BCI			o	o						o							Motor functions metric
14	Shen Gong robotics: BCI-driven rehabilitation training system			o	o						o				o			Feasibility and efficacy
15	Music intervention based on brain-computer interface system			o	o							o	o					
16	Wearable seizure onset detection system			o	o								o					
17	Clinical diagnosis and prognosis in patients with disorders of consciousness (DOC)	o	o					o		o			o					Prognosis of consciousness recovery
18	An adaptive AR display to improve situational awareness using BCI in stressful and fatigue-inducing situations			o	o						o							
19	Portable brain-related symptom screening, monitoring and surveillance system using non-invasive electroencephalograph			o	o								o			o	o	Device specification, device connection APIs
20	Portable brain-related symptom management system using non-invasive brain stimulation			o	o								o			o	o	Device specification, device connection APIs
21	Automated seizure detection and prediction			o									o					EEG cap design, software
22	Near-infrared BCI intervention in patients with stroke			o	o								o					Bimodal fusion methods
23	Fusion of multi-modal fNIRs and EEG information for motor imagery classification					o					o							

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No.	Title	Standardization requirements																
		BCI ethics	Security	Signal pre-processing method	Brain signals acquisition	High performance	Trustworthiness	Analytics of BCI data	Registries	Participant identifiers	Model generation method	Intervention	Decoding Algorithm	Biometric systems	BCI experimental paradigm	Data management	Metadata format	Others
24	BCI controlled exoskeleton with seven degrees of freedom for assistance and rehabilitation applications		o	o	o													Exoskeleton control methods
25	BCI controlled wheelchair for assistance and rehabilitation													o			o	Bimodal fusion methods
26	Reading assessment apparatus (RAA)	o	o			o	o		o					o		o	o	
27	BCI-based biofeedback for accelerated learning	o			o		o	o										
28	Brain-computer interface in aerospace applications			o	o	o					o				o			
29	T-Drone	o	o			o	o	o	o	o				o		o	o	Multimedia
30	Cognitive regulation based on brain-computer interface game			o	o						o	o			o			
31	The MindGomoku: an online P300 BCI game				o			o								o		
32	Non-invasive brain signal-based biometrics system	o	o			o	o	o	o	o				o	o	o		Governance of biometrics and personal information

In this table, “o” means “required”.

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6.2 Standardization requirements analysis of collected BCI use cases

6.2.1 Standardization requirements categorization

By analysing the explicit applications of BCI technology from all the collected use cases summarized in 5.1, their potential standardization requirements for BCI technology are further extracted, which can be categorized into six classes:

a) Fundamental standards

To reach a universal understanding of BCI-relevant concepts, it is important that fundamental standards are explored first, including BCI terms and definitions, reference architecture, heterogeneous system interoperability, etc.

b) Standards for brain information acquisition and feedback

Understanding the brain (information acquisition) and regulating the brain (information feedback) are of the most importance for brain science research, and BCI technology is evolving from one-way command output to two-way brain-computer integration. It is important that brain information acquisition standards and data fusion specifications under multiple modes are established, e.g. interface specification of signal acquisition sensors and equipment, protocol specifications, metadata format, paradigm, and operation specification of neural regulation under multiple modes, etc.

c) Standards for brain information analysis

Brain information analysis is the interpretation and analysis of brain information data by means of data processing involving normal brain function or abnormal brain diseases. The required standards are mainly divided into brain information data pre-processing and brain information encoding and decoding methods.

d) Standards for BCI applications interface

With the rapid development of BCI technology in recent years, its application fields and scenarios are expanding. It is important that extensive use cases are collected first regarding these applications, such as medical and health care, entertainment, and education. On this basis, standards, or specifications in terms of scenario analysis and technical requirements for a specific application interface are needed.

e) Standards for BCI ethics and security

BCI technologies raise a variety of security and ethical considerations, and the standards include robust features that will safeguard the mental privacy of those who use the devices, including in relation to the capture of data, processing of data, storage and exchange of BCI-related security data, security of BCI programming code, and privacy and security evaluation in BCI implementation. This will also include features that protect users from forms of hacking or manipulation that negatively impact the privacy, perception, safety (physical or mental), autonomy or identity of users.

f) Standards for BCI data communication protocols

At present, invasive BCI and non-invasive BCI systems transmit data through various transmission methods. Considering the large scale of brain signal data and the performance requirements of brain-computer interface systems, especially real-time brain-computer interface systems, it is important to efficiently transmit real-time data between the signal acquisition devices and the information processing platform. Therefore, it is crucial to standardize the requirements of the communication protocol and communication technology to improve the quality and accuracy of the signal, the processing efficiency, and the scalability of the system.

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6.2.2 Standardization requirements statistics

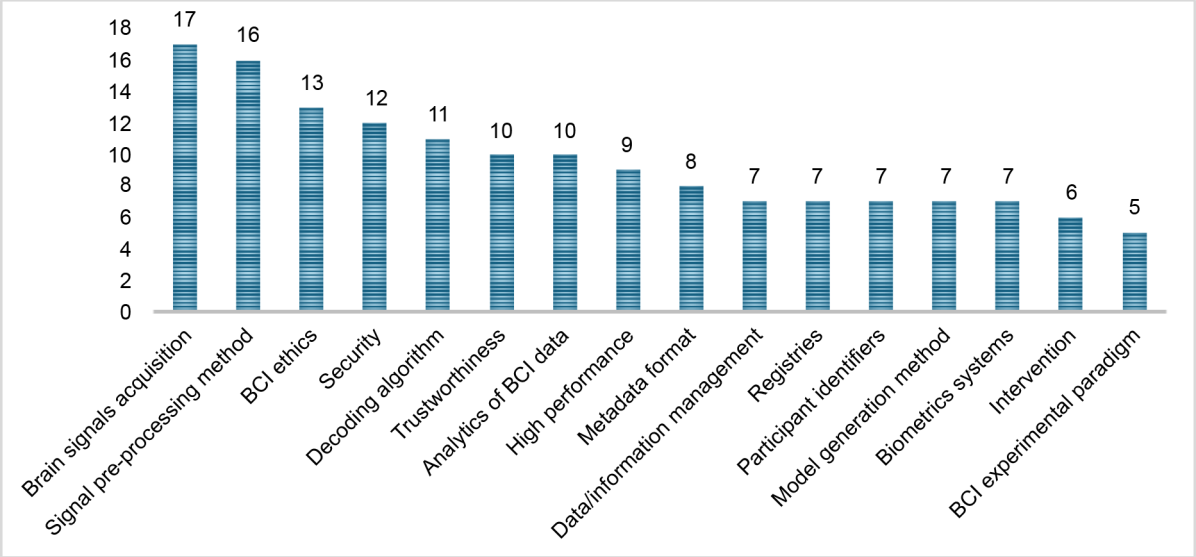


Figure 6 – Standardization requirements statistics of the collected BCI use cases

Figure 6 shows the statistics on standardization requirements from the above 32 BCI use cases. Currently, BCI requirements are based not only on technological considerations but also on societal requirements, such as BCI ethics, security, and trustworthiness. Figure 6 shows that BCI ethics and security are two important requirements of BCI standardization for 32 use cases. Especially over the last few years, the application of BCI in the fields of medicine and health has increased tremendously. The ethical requirements of clinical use cases can be grouped by fair subject selection, informed consent, respect for subjects, and so on. For example, it can be challenging to obtain ethically informed consent from patients (e.g. patients with disorders of consciousness) due to their motor deficits, communication difficulties, and the lack of alternatives. However, more attention to standardization policies can help maximize the chance for patients to obtain adequate information, maximize their understanding, and voluntarily participate in the study.

Furthermore, security is another important issue in standardization requirements. On the one hand, invasive BCIs present a major safety risk because they involve operations such as craniotomy and the implantation of probes into grey matter. On the other hand, the application of BCI involves many fields, such as prevention, diagnosis, rehabilitation, education, entertainment, and games, as shown in the use cases. The collection of personal medical data imparts vulnerability to privacy and security. Therefore, standardization, such as neural signal desensitization and usage restriction policies of BCI signals, can be designed to mitigate BCI privacy problems and security challenges.

6.2.3 Standardization requirements discussion

One complete brain-computer interaction system includes neural signal acquisition, experimental paradigm design, neural signal decoding, machine interfacing, etc. At present, the brain-computer interaction system has great differences in the above four key steps, which leads to the process complexity of constructing the BCI and interactive system, the difficulty of system performance evaluation, and the difficulty of promotion. Considering the refinement of common parts in the brain-computer interaction system, the establishment of interaction standards is of great significance, including the following:

a) the collection of neural signals that involves the equipment standards for collecting brain signals and the characterization standards of the collected signal data;

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b) the decoding of signals that involves the input standard of the decoding algorithm and the standard of the decoding algorithm during pre-processing, training, and testing steps;

c) machine interfacing that involves input data standards, equipment, and interface standards.

Specifically, the following standardization requirements can be considered first.

1) Standardization of neural signal acquisition equipment. This standardization primarily pertains to implantable equipment or implanted sensors designed to acquire spike, ECoG, local field potential (LFP), and other brain signals. According to the difference in recorded signals, it is crucial to establish a unified standard for the material and safety of the equipment.
2) Standardization of neural data representation. The neural signal forms collected by signal acquisition devices are different, and the signal pre-processing on the collected neural signals performed by the experimenters is also different. This difference will increase the difficulty of decoding system performance evaluation. Therefore, the formulation of data representation standards for neural signals is particularly important.
3) Standardization of experimental paradigm. This standardization refers to the behavioural normative model followed by the experimental object during the experiment. The extraction of neural signals is carried out during the experimental paradigm. It is conducive to standardizing the recorded neural data by standardizing the experimental paradigm.
4) Standardization of decoding algorithms. It is mainly about the standardization of the decoding algorithm interface, which is beneficial to improve the scalability of the brain-computer interaction system. Only developing the standard decoding algorithm interface can facilitate the addition of new decoding algorithms to the brain-computer interaction system.
5) Standardization of intelligent machine interfacing. Since there are many hardware manufacturers that produce intelligent machines for brain-computer interaction, their control interface is complicated. Therefore, the standard development of a unified intelligent machine control interface is more convenient for the development of brain-computer interaction systems.
6) Input standardization for feedback information. The input of feedback information is the key point and is a difficulty that two-way BCIs solve. Standardizing the information input can make the entire brain-computer interaction system more stable.
7) Characterization standardization of multimodal information. It mainly refers to the representation of sensory information, such as vision, hearing, and touch, which is conducive to more consistent information feedback input.
8) Standardization of ethics and safety. The ethics and safety of BCIs mainly include safety, humanity and personality, autonomy, informed consent, responsibility, discrimination, and justice. To avoid negative impacts, it is important to formulate standards for data security, system security, ethical design, and security assessment.

6.3 Conclusion

From the 32 selected BCI use cases, it is found that BCI technology is gradually being applied to many real-world application fields, including smart environments, medical and health, education, industrial control, and gaming. In the future, this technology will bring new changes and developments in more fields. Therefore, to ensure that BCI technology can better benefit humans, it is important to carry out standardization research work on the technology, which mainly focuses on the standardization of BCI technology, ethics and safety.

7 Use cases

7.1 Overview

This document collected 32 use cases. Subclauses 7.3 to 7.8 provide details on each use case, listed by application domain. Annex A presents the figures from all the collected use cases. Annex B contains a blank template that is used for collecting use cases.

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7.2 General information on use case

General information on the use case includes the following items.

– **Use case title**: Use case title provided by the use case contributor.
– **Application domain**: The application domain of the use case; includes but is not limited to security and authentication, smart environment, medical and health, learning, education and training, industrial controls, and gaming.
– **Status**: The status of the use case; includes prototype, proof of concept, and in operation.
– **Source**: The source of the use case; includes but is not limited to peer-reviewed scientific or technical publications on BCI applications, patent documents describing BCI solutions, high-quality company whitepapers and presentations, and publicly accessible sources in sufficient detail.
– **Scope**: The scope defines the intended area of applicability, limits, and audience.
– **Objective(s)**: The intention of the system; what is to be accomplished; who or what will benefit.
– **Narrative**: Descriptions of the (short and complete) use case.
– **Stakeholders**: Stakeholders are those that can affect or be affected by the BCI or BMI system in the scenario, e.g. organizations, customers, third parties, end users, community, environment, negative influencers, bad actors, etc.
– **Scenario sequence**: The scenario sequence is a step-by-step description of the scenario.
– **Benefits**: Benefits describe economic and social benefits.
– **Challenges and issues**: Descriptions of challenges and issues of the use case.
– **Standardization opportunities or requirements**: Descriptions of standardization opportunities or requirements that are derived from the use case.
– **Terms and concepts used**: The terms and concepts used here are consistent with existing IEC and ISO definitions.
– **References**: References are references to originator or organization and any relevant links.

7.3 Smart environment

7.3.1 Passive brain-computer interface-based adaptive automation (use case 1)

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ID	use case 1
Use case title	Passive brain-computer interface (pBCI)-based adaptive automation (AA)
Application domain	Smart environment
Status	Proof of concept
Source	[a] Calhoun, G. Adaptable (Not Adaptive) Automation: Forefront of Human–Automation Teaming. Human Factors, 2020, 64(2), 269–277. https://doi.org/10.1177/00187208211037457. [b] P Arico, G Borghini, G Di Flumeri, et al., Adaptive automation triggered by eeg-based mental workload index: A passive brain-computer interface application in realistic air traffic control environment. Front Hum Neurosci, 2016. 10: p. 539. [c] P Arico, G Borghini, G Di Flumeri, et al., Passive BCI in operational environments: Insights, recent advances, and future trends. IEEE Trans Biomed Eng, 2017. 64(7): p. 1431-1436.
Scope	A passive BCI (pBCI) monitors operator's mental state and adaptively initiates changes for automated human–machine interaction system.

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Objective(s)	A pBCI-based adaptive automation offers a human-centred approach to solve operator awareness or mental load management problems and improve working safety and efficiency by adaptively changing the level of system automation based on operator's mental states.
Narrative	Short description Mental states, like mental load, fatigue, affectivity, etc., are real-time decoded from brain signals like EEG when an operator is working in cooperation with an intelligent automated assistant (which can control a certain part or the entire system) in safety-critical applications. The automation level (the task allocation between the operator and the assistant) can be dynamically adjusted according to the real-time mental states. A typical approach is to allocate more tasks to human operator when he or she is in good working state and reduce task load to human operator when he or she is less reliable.
	Complete description Effective collaboration between human operators and intelligent agents is an important topic in safety-critical workplace like crewed spaceflight, industry production line, transportation, etc. The uncertainty of human operator status is an important factor that affects the performance of human–machine interaction. An adaptive automation (AA) system that can dynamically assign tasks between human operators and intelligent agents according to human's functional status is a potential approach to address this issue. Research team from Tianjin University designed and implemented a passive brain-computer interface (pBCI)-based AA system for a simulated flight task (SFT). The pBCI-based AA system can monitor human operators' mental load and fatigue by decoding real-time EEG when the operators are working with an agent in the SFT. The agent can take over part or all of the task. Subtasks of the SFT can be dynamically allocated to the human operator or the agent according to the real-time decoded mental state during a flight. Experimental results showed that the proposed AA system can enhance operator's situation awareness and behavioural performance and reduce mental load in a difficult task. See Figure A.1.
Stakeholders	Stakeholders would include but not limited to human operators in the human–machine system, like crews during flights, drivers and passengers in transportations, etc.
Scenario sequence	1) A human operator wears an EEG device when working in a safety-critical workplace. 2) The EEG device is connected to a computer on which the EEG-based mental state decoding software and the AA system are running. 3) Mental state of the operator is decoded in real-time and fed into the AA system. 4) Subtasks are dynamically reallocated to the human operator or the intelligent agent by the AA system according to the operator's mental state during the task.
Benefits	1) Proof of concept of the pBCI-based AA system has been demonstrated in a simulated flight task. 2) The proposed AA system can enhance operator's situation awareness and behavioural performance and reduce mental load in a difficult task. 3) The proposed AA system can provide a potential approach for mental load and situation awareness management in safety-critical workplaces like crewed spaceflight, industry, transportation, etc.
Challenges and issues	1) Mental states are difficult to be accurately decoded in practical situations. 2) Brain signal recording systems are not portable and comfortable enough for long-term applications.
Standardization opportunities or requirements	1) Brain signals acquisition systems. 2) Signal pre-processing methods. 3) Machine learning-based mental states decoding methods. 4) Mental states-based adaptive strategies for task reallocation between human operators and intelligent agents.
Relevant standards or SDOs	Not applicable

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Terms and concepts used	passive brain-computer interface; adaptive automation
References	
Notes	Describe notes if it is necessary.

7.3.2 BCI-based smart ward system (use case 2)

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ID	use case 2
Use case title	BCI-based smart ward system
Application domain	Smart environment
Status	In operation
Source	Xugang Cai, Jiahui Pan. Toward a Brain-Computer Interface- and Internet of Things-Based Smart Ward Collaborative System Using Hybrid Signals. Journal of Healthcare Engineering, 2022, 6894392. DOI: 10.1155/2022/6894392.
Scope	Control external devices through hybrid BCI-based AI technology
Objective(s)	Use hybrid BCI-based AI technology to solve the nursing and rehabilitation problems for the physically disabled, the disabled elderly, and patients with stroke, frostbite, etc.
Narrative	A BCI-based smart ward system is an integrated system combining a BCI-based AI technology control system and ward nursing scenes. A BCI-based smart ward system consists of department units, ward terminals and a HNNK™ cloud platform. Each department unit is composed of several wards and a doctor station or nurse station. The ward terminal is mainly composed of a tablet PC, an intelligent node, and a BCI-controlled nursing bed. The system collects and analyses the patients' electrophysiological signals. The HNNK cloud platform is used to upload the data and download the model. When the patients are lying in bed, they can control the external device by focusing on the visual stimuli of GUI in the smart ward system. See Figure A.2.
Stakeholders	Stakeholders would include but not be limited to medical care, researchers, clinicians, nurse, patients with physical disabilities, disabled elderly people, and patients with strokes, frostbite, and other illnesses.
Scenario sequence	1) The patients use the BCI-based smart ward system to control the smart nursing bed and intelligent equipment. The patients can control the nursing bed such as turning over, sitting up, and raising the legs without manual intervention. The smart nursing bed contains accessories of hair and feet washing tools. It also has a potty function in which the patient can go to the toilet on the bed like a healthy person. 2) The patients can access the Internet and play games according to BCI-based smart ward system. They are also able to watch TV, switch channels, and adjust the volume in the smart nursing bed. 3) The BCI-based smart ward system monitors the patients' health conditions, displays them on the terminal of the nurse station or doctor station in real-time, and automatically calls the nurses when an abnormal situation occurs. 4) The BCI-based smart ward system further monitors the patients' brain and physiological data and generates the patients' health reports. 5) The nurse station or doctor station is mainly equipped with real-time access to patient status and medical care management functions. 6) The BCI-based smart ward system generates the health reports for each patient. The doctor can manage the patients' health conditions based on the data and further customize their rehabilitation plan.

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Benefits	1) Multidimensional control; 2) High performance; 3) Low price; 4) Replace human body functions, like the third hand of a physically handicapped person; 5) Reduce the burden of nursing.
Challenges and issues	1) Provide multidimensional commands to control complex objects. 2) Minimize the burden of patients' control and ensure their safety. 3) It is important that the BCI classification accuracy is further improved. 4) It is important that the rehabilitation of patients with physical disabilities is considered.
Standardization opportunities or requirements	1) BCI ethics 2) Analytics of BCI data for people with physical disabilities 3) BCI smart home 4) BCI-based AI system for online entertainment 5) Hybrid BCI-based AI nursing and rehabilitation 6) Participant identifiers 7) Security
Relevant standards or SDOs	Not applicable
Terms and concepts used	brain-computer interface (BCI); smart ward; patients with physical disabilities
References	http://www.ihnnk.com/
Notes	Not applicable

7.3.3 Brain-machine interface (BMI) enabled assistive communication system (use case 3)

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ID	use case 3
Use case title	Brain-machine interface (BMI) enabled assistive communication system
Application domain	Smart environment
Status	Proof of concept
Source	
Scope	1) Intention detection algorithm and software with subvocal speech, imagined speech, motor imagery signal of speech, steady-state visual evoked potential (SSVEP) using signal processing and AI methods. 2) Audio or text alert about the intention
Objective(s)	Design and development of a portable BMI assistive communication system using signal processing and AI methods.

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Narrative	The BMI system processes the EEG data and predicts the intention of the user. Supported by an audio or text message integrated system to cater for the basic requirements of dependent persons – requirement of food, change in posture and daily routine needs, etc. A BMI interface-based alert or warning generation system.
	Conscious patients with severe and speech disabilities have great difficulty interacting with the environment and communicating with others. They usually require 24-hour-a-day attention and care of a dedicated caregiver. An efficient augmentative and alternative communication tool if developed for such patients can be of great utility in hospitals as well as in home care. Restoration of basic communication capabilities for these people would significantly improve their quality of life as well as that of their caregivers, increase independence, reduce social isolation, and potentially reduce cost of care. In this system, the basic needs like want of water, food, turn left, turn right, pass urine and pass motion will be identified. A portable EEG device will be used for acquiring EEG data with limited number of channels with portable EEG data acquisition and processing units. The data once acquired will be pre-processed for noise removal and frequency band selection. The pre-processed data will be used for extracting meaningful features and inputted to the machine learning or deep learning-based classifiers. If the intention or need of the subjects is identified, an audio will be played. Additionally, a text message will be shown.
Stakeholders	CDAC Thiruvananthapuram & CDAC Delhi, Government Medical College Thiruvananthapuram and AIIMS Delhi
Scenario sequence	1) Conscious but severely motor disabled patient admitted to NeuroICUs or in bed at home wears the EEG device. 2) EEG data will be captured using limited number of channels with portable EEG data acquisition and processing units. 3) The algorithm will be running in the processing unit for carrying out the activities like pre-processing, feature extraction, classification and post-processing. 4) An audio as well as text alert will be generated based on the user's intention detected.
Benefits	1) Patients can communicate their daily basic needs as a text or voice message. 2) Quality of life of patients will be increased. 3) Regular feeding is possibly not needed. 4) Need of a dedicated caregiver can be avoided.
Challenges and issues	1) It is a difficult task to identify the intention of the people who are unable to speak using EEG data. 2) Development of a clinical grade portable and comfortable EEG cap with wireless connectivity.
Standardization opportunities or requirements	1) Standardization of EEG data acquisition 2) Standardization of EEG cap design 3) Algorithm and software 4) Conversion of EEG or EOG signal into speech
Relevant standards or SDOs	Not applicable
Terms and concepts used	signal processing; feature ranking; machine learning techniques

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Notes	Brain-machine interface (BMI) technology is rapidly advancing and is expected to play a critical role in neurological rehabilitation in the forthcoming years. This technology has great potential to become a major tool for disabled patients to control locomotion and communicate with the surrounding environment and to help recovery and consequently improve the quality of their life. This technology can bring new hope to individuals who are suffering from the most severe disabilities, including people with amyotrophic lateral sclerosis (ALS), multiple sclerosis, Parkinson's disease, spinal cord injury, stroke, and other serious neuromuscular diseases or injuries. The need for such innovative technology comes from the limitations of the available rehabilitation methods to restore function for individuals suffering from severe disabilities.

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7.3.4 Monitoring and early warning technology for the fitness of special operations personnel based on EEG signals (use case 4)

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ID	use case 4
Use case title	Monitoring and early warning technology for the fitness of special operations personnel based on EEG signals
Application domain	Smart environment
Status	In operation
Source	Acceptance of patent applications: A method and device for evaluating the fitness for work status of construction workers
Scope	A BCI based real-time sensing equipment and early warning system are used to monitor and display the fitness status of operatives.
Objective(s)	The BCI-based real-time sensing equipment and early warning system are used to collect real-time EEG signals from special operators during highway construction, enabling dynamic monitoring of personnel fitness throughout the construction process and facilitating on-site safety management. This approach can effectively mitigate project safety accidents caused by human factors.
Narrative	Short description This use case embeds a non-invasive wireless EEG acquisition terminal into a safety helmet to collect EEG signals from workers during special operations such as crane machinery operations and high-altitude installations of highway construction, and uses an EEG based fitness for mental load evaluation and warning model to calculate personnel fitness index, achieving dynamic monitoring of the fitness for mental load of special workers during the construction process.
	Complete description Traditional safety management methods for engineering site workers are primarily applied in the field of site management and the identification and remediation of potential hazards. However, these methods often fail to pre-emptively address the unsafe behaviours of operators. With advancements in brain-computer interface (BCI) systems, EEG signals have been proven effective in accurately reflecting brain activity, finding widespread application in the medical and military fields. Consequently, developing EEG-based real-time sensing equipment and early warning systems for construction workers offers an effective and convenient approach to monitor and identify unsafe conditions during construction. In light of frequent accidents on highway construction sites due to unsafe conditions, a research team from the China Academy of Transportation Sciences has developed and implemented a non-invasive EEG safety helmet utilizing smart wearable technology and non-invasive EEG collection techniques. This technology allows for real-time monitoring of both EEG electrical signal data and location of workers. By combining this data with physiological parameters like heart rate, body temperature, and blood pressure, collected by other sensors, as well as cognitive and behavioural data, the research team has established an evaluation index system that includes aspects related to physiology, cognition, and behaviour. Specifically, physiological indicators such as stability, concentration and meditation are used to reflect the EEG status of the workers. Then, carry out multimodal data analysis of workers' fitness indicators, establish a work fitness index evaluation model and develop a work fitness grading standard, scientifically formulate risk control measures. See Figure A.3.
Stakeholders	Stakeholders would include but not be limited to the construction personnel and management personnel of highway engineering construction projects, waterway construction projects and other construction projects.

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