**c²AIDER: cognitive cloud exoskeleton system and its applications**

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**Abstract:** Lower extremity exoskeleton systems have been widely applied in walking assistance, rehabilitation, and augmentation-related applications merely through human-exoskeleton movement collaboration, which cannot analyse cognitive load and pressure of pilots. Cognitive exoskeleton systems can reinforce cognitive cooperation of the human-exoskeleton systems through perception and assessment. Cognitive cloud exoskeleton systems can enhance the ability of the continuous learning and transfer learning of the exoskeleton systems through cloud brain platform. This paper presents a cognitive cloud exoskeleton system Cognitive Cloud AssItive DEvice for paralysed patient (c²AIDER). The main idea is that the cooperation between the c²AIDER system and pilots is more intelligent and natural through cloud brain platform, which can achieve high-performance computing thus providing better walking assistance for pilots.

**1 Introduction**

Food and Drug Administration (FDA) defines exoskeleton system as a prescription device that is externally powered and used for medical purposes, providing mobility for paralysed people or whose lower limbs are weakened (FDA). According to the support parts of human body, exoskeleton systems can be categorised for joints, upper limbs, lower limbs, and whole body. Among those, lower-limb exoskeleton systems can be used for rehabilitation, walking assistance, and augmentation. Walking assistance exoskeleton systems are designed to help those who lost motor and sensory functions of lower limbs walking and accomplishing daily activities. Therefore, exoskeleton systems are extremely important for spinal cord injury (SCI) and attract much research effort. Consequently, many exoskeleton systems have been developed for those purposes, such as Ekso (Bionic of the United States), ReWalk (Israeli ReWalk Robotics), HAL (Cyberdyne of Japan), and Indego (ParkerHannifin of America). They are all licensed and marketed in relevant regions. The Ekso system has six freedom degrees. It can be used for rehabilitation and walking assistance for patients with lower limbs motor function injuries at several injury levels [1]. The ReWalk system helps paraplegic patients walking by driving the hip and knee joints [2]. The Indego can assist paraplegia patients sitting, standing, and walking [3]. HAL is designed for several applications [4, 5]. It helps the gait-disorder patients walking and provides augmentation.

The existed physical exoskeleton systems can only achieve physical assistance, augmentation, and gait training for the pilots through motion cooperation, which are inadequate in correcting their gait and ensuring their safety. During walking, most pilots always look at their feet to confirm they can take the next step or avoid the obstacles in front because they have no sensation in their lower limbs. However, walking assistance means not only helping the pilots moving but also correcting their gait and transmitting the environment information to them. For the purpose, the cognitive exoskeleton systems are designed to guide movement and encourage participation of the pilots by providing sensory feedback instantaneously. When the pilot make a step, he or she will immediately receive a signal which means the swing leg already step on the ground and the next step can be taken. If obstacles are in front, the cognitive exoskeleton systems will remind the pilots via stimulation signals. However, this will make the computation more complex than the physical exoskeleton systems. To solve the problem, cloud technology can be optimised to achieve high-performance computing of the exoskeleton systems. What's more, continuous learning and transfer learning can be enhanced on the cloud. Towards this end, we propose a cognitive cloud exoskeleton system Cognitive Cloud AssItive DEvice for paRalysed patient (c²AIDER) here as shown in Fig. 1. c²AIDER is considered to be an exoskeleton system based on cognitive human-exoskeleton interaction and can realise high-performance computing on the cloud brain platform. c²AIDER can realise cognitive human-exoskeleton cooperation through perception, evaluation, and augmentation. The cloud brain platform is a high-performance computing artificial intelligence platform, which combines cloud computing, big data, and machine intelligence technologies together. Data processing and sharing, intelligent analysis and decision and so on a series of complex tasks can be implemented on the cloud brain platform.

The rest of this paper is organised as follows. We propose the framework of the cognitive cloud exoskeleton system c²AIDER in Section 2. Section 3 describes the cloud brain platform of exoskeleton systems. In Section 4, we introduce the cognitive AIDER (c²AIDER) system. Section 5 presents the application of the c²AIDER system. We conclude in Section 6.

**2 Framework of the c²AIDER system**

**2.1 Overview**

In general, the exoskeleton systems are good at precise control. They can complete a task strictly according to the preset setting, but it is difficult for the exoskeleton systems to make overall planning. Humans are adept at high-level planning, but easy to get wrong in details. Based on the characteristics of both exoskeleton systems and humans, we design the c²AIDER system, which combines the advantages of both in order to efficiently complete more complex works. The c²AIDER system integrates human and exoskeleton intelligently, and high-performance computation is accomplished on the cloud brain platform. The kernel technologies are motor cooperation and intelligence enhancement, which can realise based on human-exoskeleton interaction. The framework of the c²AIDER system is shown in Fig. 2. Aiming at the complex environments and different pilots, we design multimode infusion module, physical/cognitive human-exoskeleton interaction strategy,
neural interface of pilots, and online learning strategy, which make c²AIDER combines physical motor cooperation and cognitive ability together. The c²AIDER system includes pilots interface, the brain of exoskeleton, the cloud brain platform, and the exoskeleton terminal. The pilots and exoskeleton interface, respectively, consists of multimode perception and stimulation/command receive module. The brain of exoskeleton includes physical/cognitive interaction and human-exoskeleton system decision module. The cloud brain platform takes responsibility of high-performance computation. Thanks to the cloud brain platform, data recording, storing, and processing, and so on complicated tasks are performed on it, thus reducing the heavy computing burden of the system. The physical human-exoskeleton interaction strategy uses simple human-exoskeleton interaction and kinematics data to control the exoskeleton system which aims at skeleton system rehabilitation. The neural interface focuses on both skeleton system and motor nerve rebuilding, which uses brain-exoskeleton interface to control the exoskeleton system. Some subjects need neural rehabilitation, and some need sarcous or skeletal rehabilitation (physical rehabilitation). There are also some subjects need two kinds of rehabilitation. For example, the hemiplegic subjects need neural rehabilitation in the first three months after stroke. However, physical rehabilitation will be more needed after three months to prevent them from osteoporosis. The body size of the pilots, physical parameters, and neural parameters and so on information is collected and uploaded to the cloud brain platform. The clinical assessments can be taken through the cloud brain platform according to its internal algorithm. Based on the results of the assessments, the exoskeleton system can make the training prescriptions as needed (more physical training or neural training).

Fig. 1 Concept of the c²AIDER system

Fig. 2 Theory of the c²AIDER system
2.2 Coordination between pilots and exoskeleton systems

The exoskeleton systems are hard to perceive various complex scenarios and make appropriate decisions, while human are easy to perceive current scenarios and select right direction to bypass obstacles. Pilots and the exoskeleton system should share control to complete tasks and avoid accidents. The exoskeleton systems need to detect the pilots’ intents to give appropriate assist to achieve some actions [6]. Detecting human intents relies on various sources such as physiological sensor information [7] and algorithms such as Hidden Markov Model (HMM)-based algorithm to align targets [8]. After acquiring the information, some strategies of the shared control are used to make real-time decisions. These strategies of the shared control are classified four types of role allocation [9]. The shared control strategy is shown as Fig. 3.

Co-Activity: When one task is divided into subtasks based on advantages and disadvantages of pilots and exoskeleton, they perform subtasks based on their respective advantages. For example, pilots wear the exoskeleton systems [10, 11] and keep balance, and then press the button on the crutches to give a command to the exoskeleton systems.

Master-Slave: In the strategy of the shared control, human is master who holds the final authority in emergency circumstances and exoskeleton is slave who has little autonomy and does more work. The virtual fixtures and impedance controllers are classical instances of the Master-Slave role allocation [6, 12]. This strategy is not only fit for the paraplegic or hemiplegic patients but also applies to the pilots whose lower limbs are weaker than the normal people. When in front of the obstacles, the pilots’ legs can give a little strength to the exoskeleton, and then the exoskeleton can cross or bypass the obstacles. In this situation, the pilot is master and the exoskeleton is slave.

Teacher-Student: The strategy is well applicable to train the unable limits of hemiplegic pilots using exoskeleton that learns from the motion locus of healthy limbs from the same hemiplegic pilot. In the process of training, the exoskeleton does as little of work as possible for rehabilitation of the hemiplegic pilot, while the hemiplegic pilot is encouraged to participate in the motion through the minimal assist-as-needed controller and the decayed disturbance rejection algorithm [13]. This strategy is used most for the hemiplegic pilots. The affected leg can learn correct gait track from the healthy leg when walking. From this way, the gait of the affected leg is improved to get close to the healthy leg.

Collaboration: The collaboration of human and exoskeleton demands them to carry out their communicated intentions such as the desired position at the same time, which is similar to teacher-student strategy. However, the task performance of collaboration is optimised by an interactive optimisation procedure driven by end-pilots [14].

The above strategies of shared control of human-exoskeleton are not used separately, two or more are integrated into system to adapt current situation automatically. The aim of shared control of human-exoskeleton is to make full use of their advantages, increase the task performance of human-exoskeleton, and ensure human safety.

Human-robot interaction is (HRI) devoted to mastering, designing and evaluating robot systems. The key points are individual or multiple individuals interacting with individual or multiple robots [15], and how robots interpret and apply verbal or non-verbal information. Control frame and interaction are significant for exoskeletons. Control of assistance robots for the motor injury patients is still a challenge [16]. HRI has fundamentally difference with HCI (human-computer interaction) and HMI (human-machine interaction). HRI focuses on complex systems in real environment, such as kinetic systems, auto control, and cognitive systems [17]. The controller of human-exoskeleton system can be divided into three layers. The upper controller is used to obtain human intention, environment, and exoskeleton information. The middle controller is used to transfer user intention information to explained motor output. The bottom controller is used to execute the explained motor output. Few exoskeleton systems can realise the above layer control. The most exoskeletons focus on middle and bottom control in special environment. Some exoskeletons assist pilots walking according to the established gait curve, such as ReWalk, eLEGS and so on [18]. Another exoskeletons walking according to model control method, such as HAL [19]. The research did not go deep into the processing mechanisms of various intention in real environment. Traditional interaction between exoskeleton and human can be divided into physical human-exoskeleton interaction (pHEI) and cognitive human-exoskeleton interaction (cHEI). pHEI support mechanical energy flow communication between human and robot. cHEI provides bidirectional information stream between human and robot. cHEI can be expressed by electrical signal, proprioception, and visual perception. cHEI analyses the mechanism of human behavioural intention mapping through analysis and fusion of multimode physiological and physical signals. The motor state and trend of human-exoskeleton systems can be accurately estimated through the behavioural intention mapping. The pilots’ response to physical stimulus signals and the interoperability between the pilots and the actuator of exoskeleton system are important for the cAIDER system. According to human-exoskeleton coordination control strategy and physical stimulus sensing circuits, two-way information feedback system of the pilots and exoskeleton systems is built. From this way,
cAIDER can understand the pilots' behavioural intentions. This method can make cAIDER communicate with the pilots effectively as well as enhance cognitive coordination of human-exoskeleton systems.

Walking assistance for the SCI or motor injury patients focuses not only on physical exercises or training but also on neural feedback. Some patients suffer from SCI due to the injury of motor cortex of the brain. Neural training is more significant for them than physical training. Interactive human-exoskeleton system based on EEG/EMG can analyse motor/neuromuscular motor state coding mechanism and joint decode voluntary movement [22] and reflex movement [23]. From this way, the perception and classification of human intention can be realised. According to the study of motor cortex neural mechanisms of normal subjects, the cAIDER system realises human-exoskeleton interaction interface and rebuilds the feedback mechanism of the pilots' movement sensation.

3 Cloud brain platform of the cAIDER system

3.1 State-of-art of cloud framework

The requirements of exoskeletons is growing among daily applications. However, the size and cost of the exoskeleton itself are irreconcilable with the need for computing power. Cloud robotics was proposed for solving the problems. Cloud should not be limited to completing computing migration. A powerful artificial intelligence brain based on cloud can greatly improve the robot's environmental cognitive ability and task decision-making ability. This part proposed the concept of cloud brain and discussed the cloud brain of exoskeleton systems.

At ICRA2010, Davinci cloud framework was proposed by Rajesh Arumugam [24]. The framework was described as two layers, local robots esosphere and cloud service layer. The Davinci framework was not in common use. As it cannot realise the expansion from robot to cloud if the operating system of the robot was not based on ROS, for example, the exoskeletons.

Rapyuta framework was based on elastic calculation model [25]. It can distribute safe computing environment dynamically according to Linux container technology and customisable lightweight virtualisation technology. Rapyuta framework communicate with the robot through WebSocket full duplex and can run several numbers of ROS nodes. The computing environment was closely in connection and allows robots share services and information. Rapyuta framework did not have access to the pilots' data.

UNR-RF framework composed of local platform and global platform. It was high cohesion and low coupled. The local platform has space limitations. The global platform can cover more space, and each space has its own local platform. Therefore, the UNR-RF framework needs high computing performance and large storage space of the global platform. Therefore, the UNR-RF framework has limitation of application because it needs platform layer for application scenarios.

Message queuing telemetry transport (MQTT) is current industry popular open source IoT protocols [26]. In 1999, IBM and Arcom jointly developed a protocol for the application of instant messaging scenarios, which mainly solved the problem of embedded electronic device networking. With the development of 5G network communication technology, this protocol has a good application prospect. As it belongs to the field of IOT, it can connect the data of all embedded devices in industrial production and urban activities to the cloud, thus providing data raw materials for tasks such as machine learning and data mining downstream. MQTT was developed to solve the problem of networking due to insufficient computing power of embedded services. At the same time, it also optimised network communication quality. MQTT adopts publishing subscribe message queue mechanism to decoupled and flexibly realise one-to-many, many-to-many modes at the same time. MQTT encrypt and shield the load data so that data content is highly confidential. Fragmented data transmission is adopted in MQTT because of less network bandwidth. What's more, MQTT has the exception detection and interrupt mechanism.

On the whole, MQTT can be used to connect exoskeletons. Kafka [27] is a popular open source distributed message system, which was developed by LinkedIn. Later after that, LinkedIn became a part of Apache. Open source distributed processing systems, such as Storm and Spark, have been developed in recent years and are well integrated with Kafka. Kafka has been highly praised in industry and academia in recent years. First, Kafka has high distributed structure and lateral expansibility. Zookeeper is used to manage the cluster so that the whole cluster behaves as a high-performance computer. Second, Kafka has high throughput and loose coupling. Sequential write memory partitioning mechanism and the overall adoption of publish subscription mode ensure the system efficiency and decoupling. Third, Kafka is flexible. The publish subscription model enables the whole messaging system to form a many-to-many dialogue model between producers and consumers, and the internal performance is quite flexible. Fourth, Kafka has high reliability. It can solidify the data into the hard drive and can be stored for a week by default, which makes the data flowing through was saved. From the above, Kafka is a high real-time, high reliable, high expanded system. It can ensure sensor data of exoskeletons real-time synchronisation, therefore, form instantiation on cloud platform.

3.2 Framework of the cloud brain platform

The cloud brain platform is a high-performance artificial intelligence computing platform. The cAIDER system inherits data management and processing capabilities of cloud and pay more attention to cloud-based artificial intelligence processing. With high-performance computing on the cloud brain platform, the cAIDER system can realise the following subhuman processing: (i) multi-sensors data processing of exoskeleton; (ii) evolution learning; and (iii) cooperation of multi-exoskeletons.

The cAIDER system is a new generation of exoskeleton system, which utilises the cloud brain platform for data processing, sharing, and intelligent decision-making. Multi-exoskeleton interconnection in clouds can be realised in the cloud brain platform, which makes data processing of multi-exoskeleton efficient. Multi-modal data joint processing and sharing between exoskeleton systems is possible from this way. What's more, the cloud brain platform enables the cAIDER system realise the operating of environment through multi-modal sensory information, such as vision, hearing, and touching, and perform more stable operations.

The cognitive brain consists of the cloud brain and the brain of exoskeleton system. First of all, complex computing works are translated to the cloud to execute, thus reducing the hardware cost. Then, the cloud brain realises data multiplexing, sharing, processing, and storing. The knowledge base of the cAIDER system is formed on the cloud brain platform from this way. The cloud brain provides multi-machine cooperation for multi-exoskeleton systems, thus combining the exoskeleton systems together and completing complex works. There are three main task configuration frameworks between cloud brain and exoskeleton systems. The framework of the cloud brain platform is based on (i) network exoskeletons, (ii) sensor network; and (iii) RSNP [28] model. The first framework combines service and application procedure together on the exoskeleton node. This kind of the cloud brain platform is difficult to meet the requirement of high-performance computing and is generally applied to simple tasks. The second framework contemplates the service and application procedure on cloud brain. The third framework sets the service on cloud and application procedure on exoskeleton systems terminal. Like human beings, exoskeleton systems also have sight, touch, hearing, taste, and smell. What's more, exoskeleton systems can also obtain other kinds of information through various sensors, such as motor speed, electric current, and so on. Data processing of multi-sensors can provide different perspectives and more comprehensive and accurate information for the cAIDER system to perceive the world. The cAIDER system needs to transmit sensor data, doctors and patients information to cloud. The framework of cloud brain of exoskeletons is the following.
following layers [29]. The batch layer for connecting therapist-patient data (if needed), storing pilots’ data. The rapid processing layer for transmitting exoskeleton data to cloud in order to form virtual clones at the cloud brain platform. The service layer is for monitoring, verifying, and intelligent extension. On the batch layer, database technique is used to connect PC and APP user data. IOT technology and real-time message middleware technology are utilised in the rapid processing layer.

We consider the following factors when designing the cloud brain platform. (i) Common framework of cloud brain robot has not been proposed at present. The existing frameworks are not capable for the exoskeleton systems. (ii) Each module in the framework should follow the design principle of high cohesion and low coupling, among which the generic module must be reusable. For example, visualisation component of the sensor data of each exoskeleton system should be provided for multiple exoskeleton systems. Components should be decoupled from each other without affecting other components. (iii) As the application scenario of the exoskeleton system is varying, the technical and functional requirements increase accordingly. Therefore, the framework should consider expansibility. (iv) In complex geographical environment and different applications, human-exoskeleton interaction interface is required to monitor the status of the exoskeleton and overall framework. Considering the above factors, the framework of cloud brain platform is designed including the following layers: interface, service, data, high-performance computing, and artificial intelligence. High-performance computing is the kernel component of all the cloud brain platform. The exoskeleton and pilots interface are the foundation of upper-class application. The pilots interface acts as the data input object for the entire platform. Exoskeleton serves as data output objects. Data layer includes four modules, data collection, data storage, data processing, and data intelligence. Every module can be distributed to different physical machines. Service provider offers various computing service and pilots and exoskeleton data in different regions can access to the private cloud.

3.3 Application of the cloud brain platform

The cloud brain robot is capable of transferring high-load computing tasks to the cloud and has access to a large number of data resources. It has potential applications in many fields. For example, in the field of transportation, medical, environment, financial, education, security field, and so on.

The application of cloud brain robot mainly focuses on the establishment of environment map and cognition [30]. Keho B et al. used Google recognition engine for target recognition and completed the robot grasping task with 3D vision on PR2 robot [31]. Arumugam R et al. implemented a cloud robot system named Davinci [24] based on Hadoop. After that, they built a robot system with ROS [32] as communication framework and HDFS [33] as storage mechanism. On the basis of the previous work, the cloud-slam function based on MapReduce [34] is implemented.

The cloud brain platform of the $c^2$AIDER system includes cloud intelligence, processing, sharing, storage, and supervision, as shown in Fig. 4. Cloud intelligence is used for characteristics analysis of the pilots, exoskeleton, and operation performance. Cloud processing provides high-performance framework of data processing and supports data statistics and machine-learning analysis. Cloud sharing means online updating and sharing training data, pilots’ data, and exoskeleton data. Cloud storage are permanent, redundant, and distributed. Cloud supervision includes global statistical data monitoring and overview of exoskeleton systems’ information. In the rehabilitation centre, cloud brain of exoskeleton system can provide a digital auxiliary medical treatment system for patients and therapists. On the one hand, the pilots use PC or APP to access the cloud server. On the other hand, the visual monitoring and verification of the whole scene is carried out through front-end verification and monitoring platform.

4. Cognitive exoskeleton system AIDER

4.1 AIDER system

The first generation of the AIDER system was designed in 2015 by Centre for Robotics of UESTC (University of Electronic Science Technology of China). AIDER is a bioelectrical integration exoskeleton system which is designed for walking assistance. Its principal components are electric-drive joints, mechanical linkage, intelligent shoes, lumbar support, and bind. Weight of the AIDER system is 25 kg. What's more, AIDER can walk at a speed of 0.3 m/s. Degrees of freedom of AIDER is allocated as Fig. 5 [35]. In this figure, ‘1’ means one hip degree of freedom, which is used for controlling to control the thigh up and down. The back degree of freedom ‘2’ is one and passive, which controls outward and inward pendulum of the thigh. Three degrees of freedom is assigned to knee joint to mount actuator and control the shank up and down shown as ‘3’, ‘4’, and ‘5’, which are ankle joint and have one passive degree of freedom, respectively, which realise inward and outward pendulum of ankle joints. The degrees of freedom are 5 of unilateral lower limb. The whole AIDER system has 10 degrees of freedom. The design with degrees of freedom is a rotating pair structure. The bearing are added to all degrees of freedom for supporting and reducing the friction coefficient.
order to ensure safety of the pilots, limits are set on AIDER. According to the gait curve of hip and knee joints when walking, the limit angle of hip joints is ranging from $-15^\circ$ to $35^\circ$, and knee joints $-75^\circ$ to $-15^\circ$. In addition to walking, the limit angle of when sitting down is $-115^\circ$ to $120^\circ$ of hip joints and $-110^\circ$ to $0^\circ$ of knee joints.

4.2 Cognitive AIDER system

The cAIDER system is shown in Fig. 6, which was developed in 2018. cAIDER is 23 kg and can walk at a speed of 0.5 m/s. Crutches are no longer used for controlling. For the SCI pilots whose injury plane is under T5, they can change their body posture to control cAIDER. For the pilots who suffer SCI above T5 and their upper limbs do not have enough strength, the EEG and EMG are used to recognise their intention.

Comparing with the AIDER system, cAIDER is based on the proposed cHEI. cHEI differs from both HCI and HRI because it concerns exoskeleton systems. The pilots walk with the help of the exoskeleton other than teleoperating a robot or computer. cAIDER has dynamic and complex control systems, which exhibit cognition and intelligence in real-world environments. Specifically, cAIDER is capable of avoiding obstacles or hazards, monitoring the environments and ‘safing’ itself when an emergency occurs. When making a decision, cAIDER has self-awareness, which does not mean it is sentient, but is capable of deciding what it can do and what the pilots can do, and decides when it should ask for help or solve the problems on its own. What's more, cAIDER is able to adjust itself to different pilots and then adapts its behaviours as needed. For instance, it can process information which is received from a novice differently than that received from an expert. cAIDER recognises the pilot is a novice or an expert through several information, such as gait, position, EEG/EMG signals, operations, and so on. For a novice, he may make misoperation when training and his gait is unversed. In this case, cAIDER may remind the pilots of operating methods with prompt tone and slow down its walking speed. On the contrary, an expert is skillful in operation and his gait and EEG/EMG signal are stable. cAIDER only need to alarm when the obstacles are in front, low battery, misoperation (experts may also make mistakes) and so on. cAIDER may learn and build the novices and experts models online when training and store the pilots’ information.

However, the cAIDER system also has some disadvantages. As the function is strengthened, the computational burden of the cAIDER system is increased accordingly, which makes the response speed slower than the AIDER system.

5 Application of the $c^2$AIDER system

The $c^2$AIDER system is used for walking assistance, rehabilitation, and augmentation. The pilots’ body size database, physiology database under different scenes and stages, and exoskeleton database can be built on cloud brain platform. Data sharing, storing, monitoring, and processing are realised on the cloud brain platform. The cloud brain can improve decision-making, learning, integration, and cognitive interaction ability of the $c^2$AIDER system. It can fit the pilots’ body size and make gait training processes as needed.

Walking assistance: According to gait training and assessment data, the training prescription is formed on the cloud brain platform. Pilots use the $c^2$AIDER system for gait training by following the individual prescription. For community walking, $c^2$AIDER recognises different surfaces and landforms of the ground. The old or people who lack strength of lower limbs can use it for daily walking. $c^2$AIDER lasts four hours on a charge in general which is enough to meet daily behaviours. The $c^2$AIDER system has already helped >100 people standing and community walking. A two-week clinical training of 24 paraplegia subjects with using the $c^2$AIDER were taken in three rehabilitation centres. This experiment has passed the ethical review of West China Hospital of Sichuan University. The clinical assessment results such as 6-Minute Walking Test (6MWT), 10-Meter Walking Test...
the old or people whose lower limbs are weaker than the normal without any extra assistance. The results show that the here, we have introduced a cognitive cloud exoskeleton system. c-AIDER then feed the environments and gait information back to the pilots. From this way, c-AIDER may help the pilots rebuild neural circuit and expand the active areas of motor cortex after training for a long time. The therapists can view the training data and healthy conditions of the patients on the cloud brain platform and adjust the prescription as needed. Among the proposed 24 subjects, a 15-year-old boy who suffered from intracranial injury could not keep balance for 5 min when he is sitting in a chair before training. After the two-week training, he can keep balance for 6 min when sitting and can keep his legs using the exoskeleton without any other help of therapists. Other subjects needed the therapists' help to keep balance when walking with the exoskeleton at first. After two-week training, they can sit, stand, and walk with the exoskeleton without any extra assistance. The results show that the c-AIDER system can make a significant impact on their balance.

Augmentation: Many pilots are injured in lower limbs but they can walk with the help of walker or parallel bars. Their lower limbs are not unconscious, but weaker than the normal people. c-AIDER can provide motor augmentation for them. What's more, it can help the old or people whose lower limbs are weaker than the normal carry heavy loads. In this way, their quality of life can be improved.

6 Conclusions and future works

Here, we have introduced a cognitive cloud exoskeleton system c-AIDER and its applications. The proposed c-AIDER system is more intelligent than the physical exoskeleton systems. What's more, the cloud brain platform can realise high-performance computing for the c-AIDER system, which reduces the computing burden of the exoskeleton. In addition, we showed the applications of the c-AIDER system which include walking assistance, rehabilitation, and augmentation.

New trends are moving in the direction of assist-as-needed, which is called natural interfaces. The exoskeleton systems will be true safe, portable, robust, and reliable. Specially, the exoskeleton systems can compensate the weak leg and support the needed force for the pilots. Furthermore, the exoskeleton technology can be extended to hemiplegic rehabilitation, industrial booster equipment, and military augmentation.

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