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研究課題名（和文）Multimodal Deep Learning Framework for Intelligent Brain Computer Interface System

研究課題名（英文）Multimodal Deep Learning Framework for Intelligent Brain Computer Interface System

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研究成果の概要（和文）：本研究では、視覚データ、および脳データの相関関係を学習するためにマルチモーダルアプローチを使用するBMIシステムを開発した。このシステムは、ユーザーが物を掴むなどの動作を想像すると、動きを制御し実行させる人間のようなロボットアームを用いる。物体認識機能により、物の形状に合わせ、アームが自動的に握り方をユーザーの意図に合わせ変化させることを可能にした。
さらに、脳のデータから物体の視覚画像を復号する方法を提案した。この方法では、ディープラーニングによって、脳のデータとオブジェクト画像の符号化共同表現学習を行う。システムの学習後、脳内データ符号化のみが提供され、対象画像を再構成することを可能にした。

研究成果の学術的意義や社会的意義
A brain machine interface is a technology that will revolutionize the way people interact with external devices in the future. In this research, our system can be used to augment the capabilities of users to perform multiple tasks by controlling an intelligent semi-autonomous robotic arm.

研究成果の概要（英文）：We developed a BMI system that incorporates a multimodal approach to learn the correlation of the context of a task, visual sensory data, and the brain data. The platform to test this system consisted of a human-like robotic arm controlled with a BMI. The proposed arm can be activated (i.e. grasp action) when the human operator imagines the grasping action. Since there are different ways that the arm can perform the action (i.e. different grasping configurations) depending on the context (i.e. type of the object), the arm can recognize the object and choose the best grasping configuration. Moreover, we proposed a method to decode visual shape of the objects from brain data. More specifically, we recorded EEG data during an object-grasping experiment and use the EEG to reconstruct the image of the object. To achieve this goal, we developed a deep stacked convolutional autoencoder that learned a noise-free joint representation of the EEG and object image.

研究分野：ブレインマシンインターフェース

キーワード：BMI　ロボット　脳波　EEG

１．研究開始当初の背景

Humans have always tried to enhance and augment their cognitive and physical capabilities. The research field of human body augmentation aims to explore methodologies and artificial external devices originally designed to substitute a lost limb - such as a hand prosthesis - to increase the physical capability of body-abled individuals. The question remains on whether humans will be able to control body augmentation devices directly with their brains. It is not until now that recent advancements in robotics and neuroscience are enabling the development of key technologies that may finally allow humans to augment their capabilities by adapting to new external interfaces and perhaps integrate them into their sensorimotor representation.

Previous studies have proposed body augmentation devices such as exoskeletons that augment the strength and/or endurance of the human. Other researchers have developed supernumerary limbs in the form of wearable robotic arms or fingers that are able to support heavy objects, grasp multiple objects, or play instruments. The methodologies to control these devices range from manual operation through a joystick, to using muscle impulses from real limbs. For instance, Bretan it et al. presented a study in which a robotic prosthetic limb with an attached drum-stick end effector - originally intended for an amputee drummer - was attached to the shoulder of the drummer and was activated by foot to simultaneously to play music in collaboration with the real hands. Llorens-Bonilla it et al. presented two additional robotic arms worn through a backpack-like harness that tracked user's hands to activate and assist the user by holding objects, lifting weights and streamlining the execution of a task. In these cases, the system receives a control command by decoding the user's intention through the movement of the body part, but the user is unable to use the same body part for a different task. Truly augmenting human capabilities would involve allowing an operator to perform a task with the assistance of an SRL while freeing the user's own limbs to perform another independent task in parallel. In this sense, the system needs to decode the user's intention without considering the movement of other body parts. This could be possible if the intention of the user is decoded directly from the signals of the brain.

Brain Machine Interfaces have allowed the monitoring of neural activity from brain areas such as sensorimotor cortex through, bypass the activity of the muscles, and deliver control commands to an external assistive device such as a virtual keyboard, a wheelchair or a robotic arm, to assist patients with motor paralysis conditions. Although a great progress has been made in developing BMI systems, there are limitations - such as the insufficient low throughput information or the recognition of few mental commands - that hinder BMI system's operability to control SRLs for complex tasks that require many degrees of freedom. Nonetheless, our recent efforts to develop a brain controlled SRL have produced promising results that demonstrate that BMI systems can also be used for physically-able subjects. Not only experiment participants have achieved controlling a robotic arm with a BMI to achieve a single-task (grasping a bottle), but they have also achieved parallel-tasking by doing two different actions simultaneously (grasping a bottle, while balancing a ball with their own arms), as shown in figure 1.

a)　　　　　　　　　　b)

Figure 1 Brain-controlled SRL: a) single-task (object grasping). b) User controls SRL for one task while using real arms for a different task

While our research overcomes certain BMI limitations, there are more complex actions that the SRL is unable to achieve due to the lack of mechanisms to understand the environment and interaction context; such as, grasping different objects with optimal grasping configuration (with same BMI-based command), collaborate with the user to achieve a joint task, etc.

２．研究の目的
The key objective is to provide intelligent capabilities to the SRL so it can achieve the user's intended action according to the environmental context and thus obey the user's brain-based mental command. For instance, the proposed system will consist of a human-like robotic arm that can be activated (i.e. grasp action) with a non-invasive EEG-based BMI when the human operator imagines the goal-oriented action (Figure 2). Since there are different ways that the SRL can perform the action (i.e. different grasping configurations, speeds of movement, force of grasping) depending on the context (i.e. type, position or texture of an object and interactions with other persons), physical cameras were integrated to the SRL so it can sense the environment and recognize the context of the task in order to optimize its behavior to match the user intention.

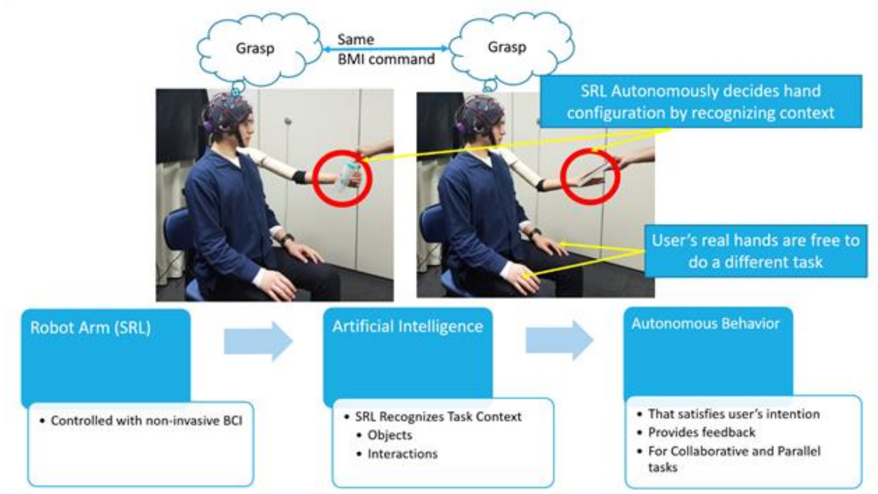
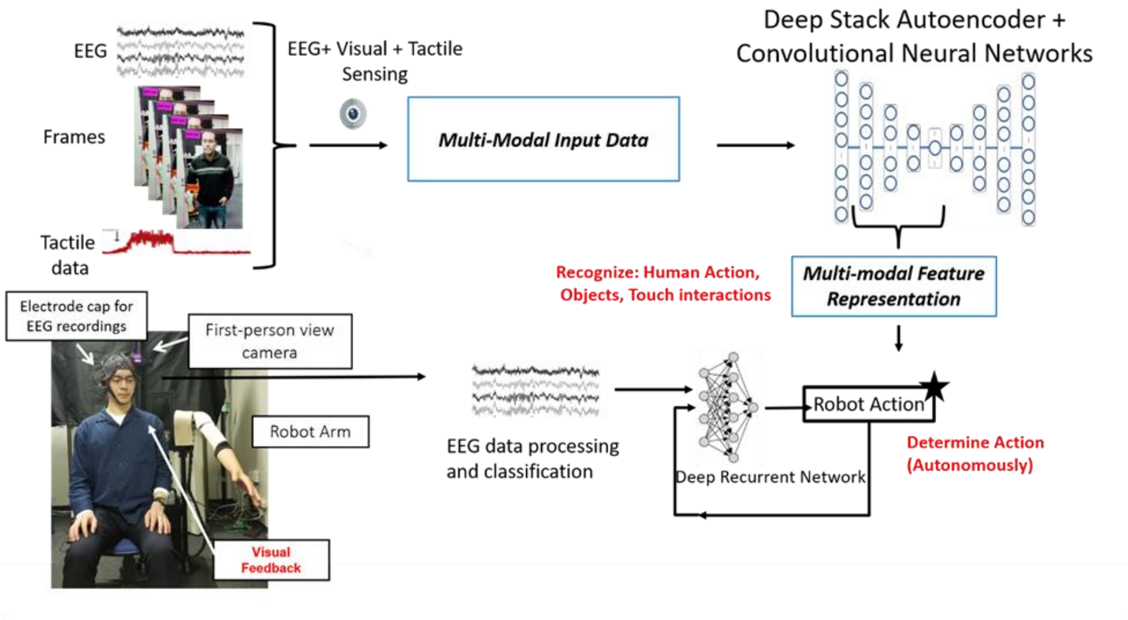


Figure 2 Brain-controlled Intelligent Robot Limb

As a result, the SRL can increase the number and complexity of actions that it can perform with a single brain-based command and the operator's real arms will be free to perform a parallel task. Moreover, the context aware capabilities allow the SRL to recognize the actions of the user (performed with the real limbs) and assist the task in a collaborative way. The proposed research opens the possibilities to develop and test more complex and realistic augmentation devices for future humans and interactions.

３．研究の方法
The research plan considered the potential system architecture and operability shown in Figure 3. The human-like robot arm was equipped with a camera that acquires first-person visual data. The operators were asked to do a task with their own arms and controlling the robot arm to do a different task by generating a brain-based command (i.e. Motor Imagery). A novel proposed deep learning framework takes multi-modal input data to learn the correlation among visual-tactile data, context of the task (object recognition and human action recognition) and operator's mental intention (i.e. Motor Imagery based hand grasp). After a decoder is learnt from multi-modal feature representation, a deep neural network can predict the appropriate action that meets user's intention to assign the command to the robot.



４．研究成果

We developed a BMI system that incorporates a multimodal approach to learn the correlation of the context of a task, visual sensory data, and the brain data. The platform to test this system consisted of a human-like robotic arm controlled with a BMI. The proposed arm can be activated (i.e. grasp action) when the human operator imagines the grasping action. Since there are different ways that the SRL can perform the action (i.e. different grasping configurations) depending on the context (i.e. type of the object), the arm can recognize the object and choose the best grasping configuration. Moreover, we proposed a method to decode visual shape of the objects from brain data. More specifically, we recorded EEG data during an object-grasping experiment and use the EEG to reconstruct the image of the object. To achieve this goal, we developed a deep stacked convolutional autoencoder that learned a noise-free joint representation of the EEG and object image.

５．主な発表論文等

〔雑誌論文〕（計　1　件）

Christian I. Penaloza, M. Alimardani and S. Nishio, “Android Feedback-based Training modulates Sensorimotor Rhythms during Motor Imagery,” in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. PP, no. 99, pp. 1-1. doi: 10.1109/TNSRE.2018.2792481

〔学会発表〕（計　2　件）

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Christian I. Penaloza, David Hernandez-Carmona, Decoding Visual Representations of Objects from Brain Data during Object-Grasping Task with a BMI-controlled Robotic Arm. In Proceedings of 4th International Brain Technology Conference(BrainTech 2019), Tel Aviv ,Israel, March 4-5, 2019.

〔図書〕（計　　件）

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〔その他〕
ホームページ等

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