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Brainwaves driven human-robot collaborative assembly

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ABSTRACT

This paper introduces an approach to controlling an industrial robot using human brainwaves as a means of communication. The developed approach starts by establishing a set of training sessions where an operator is enquired to think about a set of defined commands for the robot and record the brain activities accordingly. The results of the training sessions are then used on the shop floor to translate the brain activities to a set of robot control commands. An industrial case study is carried out to assist the operator in coordinating a collaborative assembly task of a car engine manifold.

1. Introduction

During the last a few decades, electroencephalography (EEG) has been used to analyse and understand the behaviours of human brains. By using different sensory technologies, researchers were able to develop approaches that have contributed to the medical treatment of many brain-related diseases. Meanwhile, companies around the world have introduced several equipment to capture and analyse brain signals. The functionalities of these equipment have also been significantly improved over time due to the rapid advancements in sensor technology.

Nevertheless, it has been realised that capturing the EEG signals accurately and consistently is a complicated task. This complexity is related to the fact that the brain behaviour depends on different factors, one of which is how activities are triggered in the different parts of the brain. Another factor is how the brain was originally developed, which can vary for different individuals. Furthermore, the facial muscles of an individual can also contribute to the complexity of the captured signals. Due to the fact that these muscles can generate signals which might interfere with the EEG signals, they need to be filtered out properly.

The advanced technologies in analysing the brain EEG signals show the potential in using the signals for communication with different manufacturing equipment such as robots or machines. Therefore, different methods have been defined towards what is called Brain Machine Interface (BMI). This direction of research opens the door for closer human-robot collaboration (HRC) in several challenging conditions on a shop floor. HRC aims to realise an environment where a human can work side by side with a robot. In such a collaboration setup, the human and the robot share the same resources and in some cases the same tasks. The main objective for the collaboration is to integrate the robot's repeatability with the human's flexibility. The robot's role in this case is to assist the human in tasks like assembly for instance.

Using the brainwaves for communication with a robot offers two major advantages: (1) it allows an operator to control a robot while performing a related task to co-work with the robot, which will have a positive impact on the productivity at the robotic cell level; and (2) it provides an auxiliary channel for multimodal collaborations with the robot in addition to voice, gesture and haptic commands. For example, using mental commands to control the robot can overcome the difficulties that often accompany the usage of voice commands in a relatively noisy robotic environment.

The remainder of this paper is structured as follows. Section 2 describes briefly the related work with respect to the presented approach. Section 3 explains the developed system; the detailed description of the approach is presented in Section 4. Section 5 depicts how the human brainwaves are translated into robot commands. An industrial assembly case study is implemented and the results are outlined in Section 6. Finally, Section 7 concludes this paper and identifies the future work along this research direction.

2. Related work

Since the dawn of industrial robots, several attempts have been made to establish collaborations between robots and shop floor operators. These collaborations were achieved via several channels of communications. At the beginning, the communication with a robot was mainly based on the teach pendant connected to the robot controller. Several research groups such as Ref. [1] focused on establishing more flexible communication between the teach pendant and the robot controller. At the same time, researchers [2] started developing smartphone-based software to replace the conventional teach pendants. The usage of the smartphones opens the door for more intuitive communications between humans and robots (e.g. voice command, augmented reality, etc.). Meanwhile, others were focused on developing a computer-based graphical user interface to control a robot using an external computer [3,4]. Furthermore, force control [5] was used to facilitate a close collaboration between the human and the robot.

Despite the efforts, establishing a natural and intuitive channel of communication between humans and robots is still a significant

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challenge and it requires further investigations. Using brainwaves to communicate with a robot shows a great potential for the future. Many research efforts [6,7] were devoted to control humanoid robots by analysing human EEG signals and translating them into a set of commands. Others [8–10] focused on using brainwaves to navigate a mobile robot in an unknown environment.

During the past years, several approaches have been developed to control a large variety of robots. One of these approaches is the work presented in Ref. [11], investigating the possibility of using the human brainwaves to control a chair robot navigating in an indoor environment. Moreover, brain signals were used to control robot arms and perform a defined set of simple tasks [12–14]. Similar approaches were developed and reported in Refs. [15,16] to control robot arms using brain commands. Another work [17] was focused on controlling a vacuum cleaning robot navigating in an enclosed indoor environment.

Despite the achievements and increasing interests in brainwave based robot control, the applicability of the reported systems to realistic cases (such as human-robot collaborative assembly in industrial settings) remains a challenge. Further developments are therefore required to bridge the gap.

3. System overview

The developed system provides the ability for a shop floor operator to control an industrial robot using own brainwaves. The system can synchronise with other channels of communications (gesture, voice, etc.) to enhance the level of collaboration between the human and the robot during assembly operations. Such a collaboration aims to combine the repeatability of the robot with the flexibility of the human. It utilises the strength of both sides and enhances the quality and the adaptability of the HRC assembly operations.

As shown in Fig. 1, the system consists of four modules. Module ❶ is an engine that filters noises out from the captured EEG brainwaves and analyses the signals to identify both the human thoughts and emotional states. Module ❷ is responsible for handling human mental commands as well as the training sessions needed to recognise these commands. Module ❸ is a user interface that allows the shop floor operator to enable the mental commands, observe the robot status and follow the instructions to facilitate the collaboration with the robot. The mental commands are then sent to module ❹, a robot interface, to control the robot and assist the collaborative assembly. As illustrated in Fig. 1, the EEG headset used in the system communicates with the brainwave engine (module ❶) using Bluetooth, while the rest modules communicate via Ethernet. The interfaces among the modules and the signal processing are developed in Java.

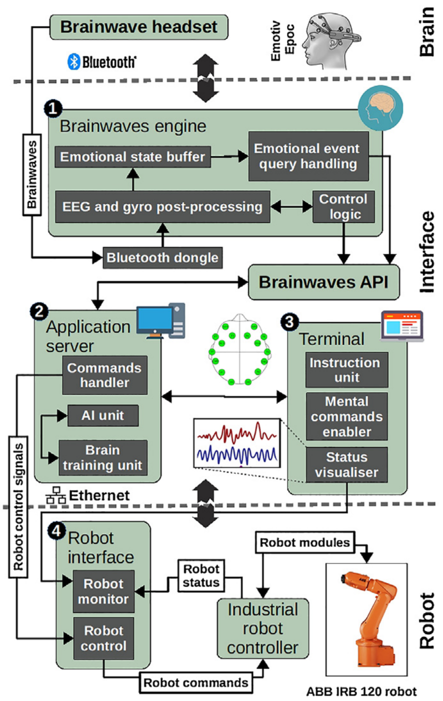

Fig. 1. System configuration.

4. Brainwaves recording and analysis

The human brain is a highly advanced organ that works with the nervous system to observe the surroundings, analyses the observed information and then coordinates the other parts of the body accordingly. Thought associated with a command leads to the activation of different parts of the human brain, which significantly relies on the brain interpretation of the word and how the brain has evolved in the early stages of life. The activity of the brain can be recorded and considered as a signature for the given command. As an example, Fig. 2 illustrates how different parts of the brain are triggered when a human is thinking to move a robot.

In this research, an Emotive Epoc+ device has been selected as the EEG measuring headset to record brain activities. The headset uses a set of 16 electrodes attached to the human scalp in multiple locations. The actual locations are defined using the 10–20 system method and connected to a Bluetooth® transmitter, where 10 and 20 refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front–back or right–left distance of the skull. Fig. 3 illustrates the locations of these electrodes along the scalp.

In order to improve the identification quality of the command's signature, multiple training sessions need to be conducted, in each of which the human thinks about the command for a short period of time (ca. 20 s) while the EEG headset records the brain signals. Here, two aspects need to be taken into consideration during the training: (1) the training needs to be performed in a quiet and static environment with minimal external disturbance, and (2) a trainee needs to avoid distractions and facial movement as much as possible. Fig. 4(A) shows a flowchart of the mental training before robot control. The procedure is performed in a sufficient number of times. The training of the system is performed in the experimental stage with more details provided in Section 6. The number of training sessions is decided based on the progress of the recorded brain activities.

Artificial neural network (ANN) is used to perform the training through backpropagation. The objective is to optimise the weights of the ANN so as to determine the relationship between the input brain thought and the output robot command. During each training session, the brain signals (input) and the expected robot command (output) are introduced to the neural network and the response is determined. The first stage is called forward pass where the ANN is fed with inputs and outputs, and assigns initial weights.

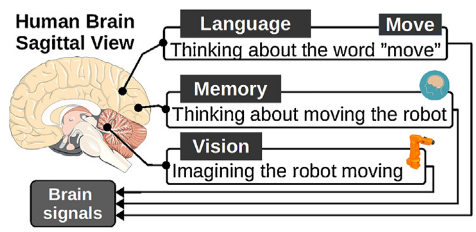

Fig. 2. Brain's reaction to a single thought.

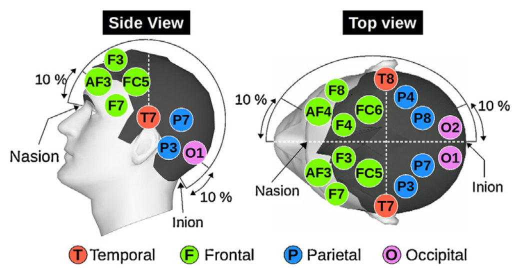

Fig. 3. Locations of electrodes based on the 10–20 system.

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