Artificial arm for manipulations in toxic atmospheres based on EEG-EMG signals

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Abstract. Industrial environments with potentially toxic atmospheres such as research laboratories or test centers are at increased risk for human operator health, especially due to the very short time they need to act to prevent fatal events at work place. In this paper we propose a solution with industrial applicability based on human arm modelling and simulation that is capable of replacing human operator's direct intervention in manipulating substances that can generate toxic vapors that affect air quality or contain substances with high epidemiological risk, or others that, in case of inappropriately manipulated, can produce potentially explosive situations. Based on an EEG-EMG solution, the human operator can control the human artificial arm remotely from a safety location only by using own electrical signals generated by the brain and the neurons network.

1 Introduction

Industrial development over the last half century has led in many industrial sectors to the widespread use of potentially toxic substances that are harmful to human health. With the periodic review of safety and health protection standards, the need to find new solutions to protect the physical and mental integrity of industry employees must become a priority.

Places which may produce dangerous atmospheres are areas such as dangerous waste sites, chemical plants, landfills, chemical plants, refineries and regions where are underground storage tanks. Hazardous atmospheres include flammable, combustible, explosive environments, oxygen deficient environments and toxic environments.

Because many tasks are unpredictable or are too costly, or many worksites are dangerous to human health, for example nuclear or biologically / chemically toxic environments, mechanical manipulation by human operators and remotely controlled video inspection are necessary for controlling the remote devices and sensory information.

When human presence is difficult or undesirable, remote human teleoperation of the human artificial arm is required. Some cases include the nuclear facilities, handling dangerous materials or disassembling bombs and operating in inaccessible sites in mining, undersea exploration. [1].

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2 Problem description

The toxic atmospheres are common in the solar cell manufacturing industry, especially due to chemicals used in the manufacturing process of wafer-based crystalline silicon solar cells, that can cause chemical burns if they are inhaled, such as in the case of smoke released by hydrofluoric acid (HF) and nitric acid (HNO₃) or alkaline substances, such as NaOH, used for wafer cleaning, reagent cleaning or oxides removal and for this reason it required a good space ventilation.

Also, a large number of substances used in solar panel industry present a high risk for human health such as: the arsine that, at a concentration between 0,05 and 3 ppm, can affect the blood and kidney, the arsenic compounds produced by Gallium arsenide used in process of thin-film panels fabrication that, at a concentration of 0,01 mg/m³, is responsible for cancer and lung disease, the cadmium compounds, used to produce thin film solar cells with high efficiencies based on deposition of CdTe and CdS substances and CdCl₂ treatment at concentration of 0,01 mg/m³ in case of dust or 0,002 mg/m³ in case of fumes, are responsible for cancer and kidney disease. [2-3].

Teleoperation is the extension of the person's capability of detecting and manipulating in a remote location. A teleoperator includes at least arms and hands, artificial sensors, a vehicle for transporting them and communication channels to and from the human operator.

Robotics is the science of performing, through an automatic machine or device [4], functions typically attributed to human beings or working with what appears to be almost human intelligence.

Telerobotics is a form of teleoperation in which a human operator behaves as a supervisor, intermittently communicating to a computer information about goals, assumptions, suggestions and orders suitable to a limited task, getting back information about raw sensory data, performances and difficulties and meanwhile the subordinate telerobot executes the task based on information received from the human operator and its own intelligence and artificial sensing [5].

3 Solution based on EEG-EMG

Robot development has always started from the model of the human body or from a part of it. That's why robotic arms know how to reproduce the movement of a human arm. This leads to the idea that, if the right sensors are used, a robotic arm can be controlled by the movements of a human arm.

Fig. 1. Proposed solution block diagram for EEG-EMG control system

Because the brain is the one who sends the motion control signals, we used 2 types of sensors to “read” the signals that are given by the brain. One type of sensors are EEGs that

can read the brainwave signals of a particular intent of motion and can reproduce it in actions based on pre-set mental commands.

In order to create a BCI connection between BCI headset and the control unit we need to use specialized software such as the Emotiv Xavier Control Panel interface which, based on the movement of a virtual object (mental tasks), acquires the EEG signals from the BCI headset and translates them into computer binary code to be understood as control signals. Through the interface there can be learned up to four mental commands such as: lift mental action (shown in figure 2), drop mental action, right mental actions and rotate mental action.

Fig. 2. Emotiv Xavier Control Panel for Lift mental action

During the training of the mental command, it is necessary that the user maintains a high level of attention and focus over the mental action that it is supposed to learn because these two key factors correspond to chemical reactions over the brain that give a high level of beta brainwave on the frontal cortex that is responsible, among many others, for conscious thoughts and imaginary actions formation presented in figure 3 as a result, from a real time recording session according to impose mental action, together with Emotiv BCI headset EEG signals quality at scalp level.

Fig. 3. 3D Brain Visualizer Emotiv Interface of beta brainwave activation for impose Lift mental action

In order to create a neural network based on an EEG solution, it is not enough just to train it, which requires, among other things, mapping each mental action to a predefined sequence of keystrokes to link the imagined movement to a robotic arm action [6]. This can be done easily using the Emotiv Xavier EmoKey as shown in figure 4.

Fig. 4. Emotiv Xavier EmoKey Interface

Also, to be able to view in more detail how it processed the EEG signals formed at brain level through the BCI interface there was used EEGLAB, a powerful open source toolbox for the MatLab environment for processing the electroencephalography (EEG) and magneto-encephalography (MEG) signals and other electrophysiological data event-related. This toolbox is based on a set of MatLab functions for processing and visualization EEG data.

EEGLAB is able to deliver a standalone graphical user interface (GUI) that allows users to interact with EEG data without the need for running a MatLab syntax [7]. The user graphic interface integrates powerful tools that provide a large number of functions placed into three individual layers for processing EEG signals (artifact rejection, filtering, epoch selection and averaging) for analysis in time or in frequency EEG data, for independent component analysis (ICA), for event-related statistics and for data visualization (scalp map, scrolling and dipole model plotting, plus multi-trial Event-related potentials (ERP) image plots [9].

EEGLAB also provides a programming environment that allows user to store, access, measure and manipulate the single-trial and/or averaged EEG data and display it hierarchized according to the number of EEG communication channels provided by BCI equipment.

Based on its functionality it can be represented (figure 5) the EEG signals distributions for each one of the five EEG channels provided by Emotiv Insight BCI headset corresponding to impose Lift mental action.

Fig. 5. EEGLAB EEG Signals Plot for impose Lift mental action

It is also able to provide a spectral analysis for every data channel using a trace of color for every particular area of the brain according to the power at a frequency between 6Hz and 22Hz, as can see in figure 6 with parieto-temporal cortex predominance.

Fig. 6. EEGLAB Spectral Analysis for Lift mental task

On the other hand, because we want to make a frequency analysis of EEG data, we use the software development kit Emotiv Xavier TestBench, a specialized software for real time analysis of electroencephalogram (EEG) signals based on Fast Fourier Transform (FFT) to represent for each channel the brainwave major frequency bands: Delta, Theta, Alpha, Beta. This SDK allows saving the recorded EEG data in European Data Format file (.edf). This can be analyzed in EEGLAB toolbox after conversion into Comma-separated Value format (.csv). The diagram of brainwaves frequencies for impose Lift mental action obtained by analyzing of AF3 data channel corresponding to frontal cortex brain area is presented in figure 7.

Fig. 7. Emotiv TestBench brainwaves analysis of Lift mental action

Another type of sensors is EMG [8] used in combination with EEG sensors solution, principally due to the fact that it is too difficult to create a complex group of movements over a several servomotors in case of artificial arm brain control because of the limited mental commands that can be use at a time and also due to the absence of the movement intention that it is given by brain over a particular group of muscles of the human arm.

For this reason, the role of EMG sensors is to read the electrical signal sent by the brain to each muscle group to make a movement. With this type of command for the robotic arm, a remote control can be made when the robotic arm is in a dangerous environment [10] and must perform certain movements that do not follow a particular pattern and have to make certain movements.

In this case, the human operator places sensors on him and is positioned in a safe area where he can observe the movement area of the robotic arm. The robotic arm is tied to the control unit and does exactly the same movements as the human operator.

Fig. 8. EMG signal aquisition

Fig. 9. Neural network based on EEG-EMG solution

Signals purchased through the Arduino prototyping system are used as input data for the neural network that had an initial training period [11].

During the training period, sets of values acquired from the EMG (figure 8) and EEG (figure 5) sensors were used as inputs in neural network together with signals taken from the IMU sensor to determine the position of the arm and are used as outputs of the network.

Following the training of the network, the two types of EMG and EEG signals are used as inputs into the neural network (figure 9), and depending on them, the position of the robotic arm is determined.

IMU type signals are still displayed to see if the value displayed on the network output is roughly equal to the value still displayed by the IMU sensor.

4 Conclusions

The EEG-EMG-based solution enables the user to manipulate a large number of substances with high potential hazard only by using his own brain signals through a neural network and in a way that gives him the capacity to view the whole process from a safe distance. In this paper we have chosen to treat a complex EEG-EMG-based solution for the control of an artificial arm because only the results offered by motor imaginary solution are not satisfying excepting the fact that electroencephalogram signals present a lower amplitude in comparison with the electromyography signals because of limited number of mental commands that can be accessed at the same time through the BCI interface and which must be combined with physical commands, such as facial gestures that can also be recognized and mapped to predefined sequences of keystrokes. This makes it impossible to generate

sequences that involve complex movements on a group of servomotors in real time being necessary to record the motion intention generated by each group of muscles to replicate the movement of the human arm. The EEG solution is also useful in limitation of human error produced by mental workload due to the capacity of recognizing the mental states that produced by the drowsiness state signalized by the increase of blink rate. Also, the EMG solution together with IMU sensors offers the advantage of constantly knowing the position of the robotic arm making it predictable to be used in precision operations that imply the synchronizing movements with the human operator.

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