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Communication with Patients in a Coma or Vegetative State using BCI

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Abstract*: This project explores the use of Brain-computer Interface (BCI) technology to enable communication with patients in a coma or vegetative state (VS). By analyzing neural signals through non-invasive methods like electroencephalography (EEG), BCIs can detect signs of cognitive awareness, even when motor functions are impaired. The goal is to develop a reliable system that allows patients to communicate basic intentions, improving diagnosis, care decisions, and patient autonomy. Ethical concerns around consent, accuracy, and quality of life will also be addressed*.

Keywords: Brain Computer Interfacing (BCI), Information and Communication Technologies (ICT),Brain wave sensor, Receivers/Decoders

I. INTRODUCTION

Disorders of consciousness (DoC) are common, with or without acute brain injury. Recent studies have identified behaviorally unresponsive patients who show volitional brain activation through fMRI or EEG, a state known as cognitive motor dissociation (CMD), which has been linked to later recovery. Despite some preserved consciousness, these patients often cannot communicate their basic needs, such as pain or anxiety, and rely on non-vocal methods like lip reading, which are often inadequate. Brain-Computer Interface (BCI) technology, which translates brain signals into commands, offers potential but faces challenges in critical care. These include distractions, fatigue, and physical limitations such as eyelid apraxia. While auditory-based BCI systems are promising, they have shown inconsistent results in ICU settings. Current cue-based BCI systems limit patient responses to pre-determined periods, whereas self-paced systems, which allow patients to activate BCIs freely, offer more flexibility but require high accuracy and low false positives. This approach may be particularly beneficial for patients with fluctuating mental states.

II. GENERAL BACKGROUND

Consider a patient left unresponsive after a dramatic accident and for whom clinicians have to decide about his cognitive status, the most appropriate health care, such as consent to interventions or withdrawal of life support, or more basically daily life situations (switch the music or television on or off…). Depending on the level of consciousness alteration, interactions with the patient may be simply not possible and these decisions will be the responsibility of third parties. This raises a number of major ethical issues: who holds responsibilities, role of previously expressed wishes…

It should also be considered that residual cognitive processes or even awareness of self and environment are preserved, or have reappeared but remain inaccessible because of motor impairment, vigilance fluctuation, or insufficient attention/work load. Beyond the assessment of consciousness, one important goal in clinical practice is the establishment of at least a yes/no code in order to restore basic communication with these patients. This illustrates the need for methods of assessing cognitive or mental states, monitoring vigilance, attention, awareness, arousal, workload… Brain signals furnish direct measures that can contribute to the optimization of these assessments, complementing classical behavioral or peripheral physiological observations. Although this idea might seem obvious, online applications aimed at communicating with patients have only recently been possible, thanks to the latest

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III. OBJECTIVES AND METHODS

***Objectives*:**

Behaviorally unresponsive patients in intensive care units (ICU) are unable to consistently and effectively communicate their most fundamental physical needs. Brain-Computer Interface (BCI) technology has been established in the clinical context, but faces challenges in the critical care environment. Contrary to cue-based BCIs, which allow activation only during pre-determined periods of time, self-paced BCI systems empower patients to interact with others at any time. The study aims to develop a self-paced BCI for patients in the intensive care unit.

Methods:

Experimental Design: The BCI system used EEG signals from the patient, decoded in real-time by a bedside computer, with sensory feedback provided through auditory and visual means. For signal acquisition, 21 EEG electrodes were applied according to the International 10–20 system by certified EEG technicians. The EEG data was collected via a standard bedside monitoring system, filtered (1-70 Hz), sampled at 200 Hz, and transmitted to the BCI computer using a TCP/IP protocol developed in Microsoft Visual C++ 2017. Real-time processing was handled by algorithms implemented in Matlab 2019a and Visual C++ on a computer equipped with an Intel Xeon processor. Auditory feedback was delivered through disposable earphones, and visual feedback was displayed on a monitor in front of the patient. A second monitor, used by the operator to control the experiment, enabled real-time tuning of decoding parameters to optimize BCI performance. Commands were given in English or Spanish based on the patient's language.

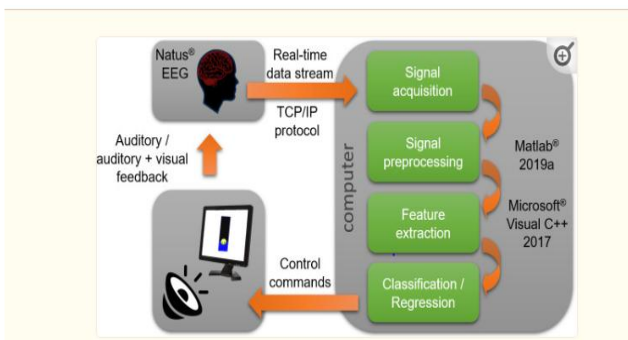

Fig 1: General scheme of the BCI system

Experimental Protocol

The experiment involved multiple sessions with ICU patients. The first session(s) were used for BCI model calibration, lasting 5 minutes each, and the final session, lasting 10 minutes, was for model validation. Patients controlled the tempo of a beeping sound and moved a bar on a screen, with breaks between sessions. Visual feedback was removed after testing with initial patients and volunteers due to visual apraxia concerns. Patients responded to auditory prompts by opening and closing their right hand, while the BCI system analyzed corresponding EEG signals every 100 ms. Calibration included partial correction using "ground truth" data (the given command) to improve accuracy, but this assistance was phased out over 3 minutes. During validation, no ground truth was used. Commands were repeated every 10 seconds, and motion/no-motion periods lasted 15-50 seconds randomly

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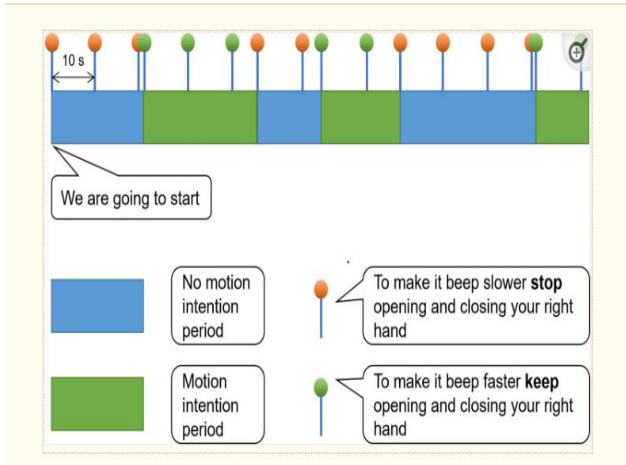

Fig 2 BCI Protocol

IV. BRAIN COMPUTER INTERFACING

4.1 Brain Wave Sensor

The communication between neurons within our brains. Brainwaves are produced by synchronised electrical pulses from masses of neurons communicating with each other. Brainwaves are detected using sensors placed on the scalp. They are divided into bandwidths to describe their functions (below), but are best thought of as a continuous spectrum of consciousness; from slow, loud and functional - to fast, subtle, and complex. It is a handy analogy to think of brainwaves as musical notes - the low frequency waves are like a deeply penetrating drum beat, while the higher frequency brainwaves are more like a subtle high pitched flute. Like a symphony, the higher and lower frequencies link and cohere with each other through harmonics. Our brainwaves change according to what we're doing and feeling. When slower brainwaves are dominant we can feel tired, slow, sluggish, or dreamy. The higher frequencies are dominant when we feel wired, or hyper-alert. The descriptions that follow are only broad descriptions - in practice things are far more complex, and brainwaves reflect different aspects when they occur in different locations in the brain. Brainwave speed is measured in Hertz (cycles per second) and they are divided into bands delineating slow, moderate, and fast waves

Fig_3 Brain Wave Sensor

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4.2 Brain Computer Interface

A **(BCI) Brain Computer System** is a system that facilitates direct communication between the brain and external devices by interpreting brain activity without requiring traditional motor functions like speech or movement. BCIs typically involve capturing brain signals through non-invasive methods such as electroencephalography (EEG), where electrodes placed on the scalp measure electrical activity generated by neurons. The captured signals are then processed, filtered to remove noise, and analyzed to extract relevant features that correspond to specific cognitive or motor intentions. Advanced algorithms, often using machine learning, decode these patterns into commands or responses, such as moving a cursor or answering a yes/no question. Feedback is provided to the user through visual, auditory, or tactile means, helping them understand and adjust their brain activity for more effective control.

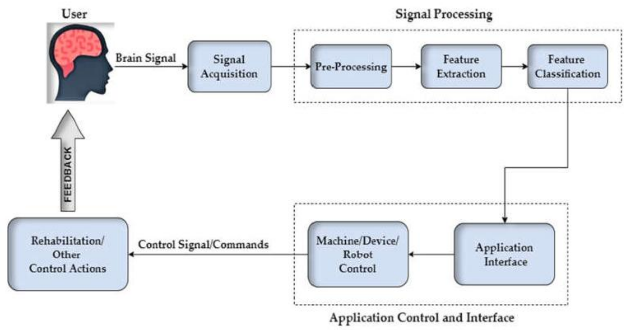

Fig_4 Block Diagram of working of BCI

BCIs are especially useful for individuals with severe disabilities, including those in a coma, vegetative state, or those with motor impairments like paralysis. For these patients, BCIs can enable communication by translating brain signals into binary responses (e.g., yes/no) or more complex commands, improving patient autonomy and interaction with caregivers. BCIs are also applied in rehabilitation and assistive technologies, helping users control prosthetics, wheelchairs, or computers.

4.3 Receiver/Signal Decoding

The REW-NPLS algorithm was chosen for signal decoding as it demonstrated high efficiency in prior BCI applications. The decoding model created by the REW-NPLS algorithm was used to predict the response variable, i.e., the intention of opening and closing of the hand, every 100 ms. During the calibration session the model was adjusted every 10 seconds, while the model was fixed during the validation session.

Brainwaves are produced by synchronized electrical pulses from masses of neurons communicating with each other. Brainwave speed is measured in Hertz (cycles per second), Brainwaves are detected using sensors placed on the scalp.Typical uses of buzzers and beepers include alarm devices, timers, and confirmation of user input such as a mouse click or keystroke. This buzzer can be used by simply powering it using a DC power supply ranging from 4V to 9V. A simple 9V battery can also be used, but it is recommended to use a regulated +5V or +6V DC supply. The buzzer is normally associated with a switching circuit to turn ON or turn OFF the buzzer at required time and require interval.

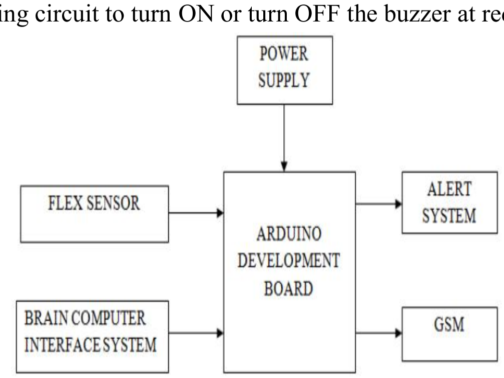

Fig_5 Block Diagram for Proposed System

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V. RESULTS AND DISCUSSION

Monitoring coma patients using Brain-Computer Interfaces (BCI) explored a groundbreaking way to understand and communicate with patients who are in a coma or have severely impaired consciousness. Normally, doctors assess these patients based on physical responses like reflexes, but this doesn't always show the full picture. By using BCIs to read brain signals, doctors discovered that around 15-20% of patients who appeared completely unresponsive actually had some level of awareness. This is a major breakthrough because it shows that these patients might still be conscious, even if they can't physically show it. The project also found that BCIs could help these patients communicate by allowing them to answer yes/no questions through their brain activity, offering a new way for them to interact with the outside world.

At the same time, there were challenges. Brain signals are hard to read clearly in a busy hospital environment, and not every patient responds the same way to the technology. There are also ethical questionsif a patient shows signs of awareness, how should that affect decisions about life support? Despite these issues, the project showed that BCIs could help track a patient's brain activity over time, giving doctors more information about their chances of recovery. Overall, while the technology is still developing, BCIs have the potential to change how we understand and care for coma patients, offering new hope for both patients and their families.

VI. CONCLUSION

We elected to only allow a small number of training sessions and validation sessions, but felt that it was important to show that the BCI system is able to work under these circumstances keeping concerns about patient fatigue in mind. Importantly, in behaviorally unresponsive patients it is particularly challenging to detect fatigue. Additionally, our cohort of healthy volunteers was not well matched in terms of gender or age distribution when compared to our patient cohort. This study was not conceptualized to comprehensively study if BCI activation in cognitive motor dissociation is possible but this question will be the focus of future studies utilizing the BCI system presented here.

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