A Game-based Learning Framework for Controlling Brain-Actuated Wheelchairs

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Introduction
Background

— paraplegic patients require wheelchairs for mobility
— some patients require motorised electrical wheelchairs
  • tetraplegics
  • upper body paraplegics
  • sufferers of amyotrophic lateral sclerosis (ALS)
  • others
— if very serious paraplegia, brain control interface (BCI) may be an option alone or together with other control inputs (e.g., voice, eye tracking and blinking, etc.)
— sufficient learning/training required before real-word use
— BCI training can be repetitive and boring
— a game-based virtual environment (VE) can motivate user, be adaptable and flexible, offer variety of virtual scenarios,
Electroencephalography (EEG)

— measurements of the natural electric potential on the scalp
— reflects number of synchronous neural discharges
— EEG frequency bands:
  • delta (< 4 Hz)
  • theta (4–7 Hz)
  • alpha (8–15 Hz): alert and cognitive states
  • beta (16–31 Hz): purposive movements
  • gamma (> 32 Hz)

⇒ delta and beta bands most relevant for stroke rehabilitation
— several good low-cost commercial-off-the-shelf (COTS) EEG equipment exists, e.g., Emotiv EPOC EEG
Motor-imagery brain-computer interface (MI-BCI)

— EEG-based MI-BCI can help paretic or paralysed stroke survivors to interact using brain waves instead of muscles
— reports on EEG-based MI-BCI combined with robotic feedback neurorehabilitation for stroke patients
— event-related desynchronization/synchronization in sensorimotor oscillatory rhythms associated with MI
— use rhythms/frequencies as inputs to BCI
— MI can replace actual physical task performance while still induce neural plasticity changes, e.g., brain wave control of a wheelchair in a computer game instead of physical joystick control
Related work

— 2005 (Tanaka et al. [1]):
  - recursive training algorithm to generate recognition patterns from EEG signals
  - used a real physical motorised wheelchair
  - slow processing times ⇒ required external assistance for stopping wheelchair during EEG detection and pattern matching

— 2007 (Craig and Nguyen [2]):
  - real-time EEG classification system
  - EEG control as supplement to head movement control
  - training with physical wheelchairs is slow, non-flexible, require medical staff during exercises

— 2007 (Leeb et al. [3]):
  - used virtual wheelchair and training environment
  - did not include game-based learning elements to improve motivation
Aim

— develop open-source game-based learning framework for control of brain-actuated wheelchairs simulated in a VE
— implement two modes: manual (asynchronous) and autopilot
— use low-cost, adaptable, flexible commercial-off-the-shelf (COTS) components
— demonstrate fast virtual prototyping (matter of months)
— implement a preliminary artificial neural network for EEG pattern recognition and control

Main components of system framework

— Unity 3D game engine for VE
— Emotiv EPOC EEG headset for brain wave control
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Game-based methodology

— combine enjoyable game aspects while learning
— key aspects of game-based learning in a VE:
  • **safe risks**: no dangerous consequences of mistakes in VE
  • **goal-based tasks**: stimulate learning through achievements
  • **incremental learning**: adapt to user progression
  • **timed events**: use game times as incentive for improvement
— employ **game levels** to achieve the above
Game levels

Five game levels have been implemented in our solutions:

1. learning/practice of **single command** (’forward’) in drag race
2. **switching of commands** while navigating in labyrinth
3. learning to handle **safety mechanisms**
4. **difficult/advanced tasks** for improving navigation skills
5. integrated the above in **realistic real-world urban navigation**
EEG data acquisition

— Use the Emotiv EPOC EEG headset

- high-resolution, multi-channel, portable system
- bluetooth wireless transmission to computer
- 14 EEG channels placed as in 10-20 system:
Training of mental commands

— use Emotiv software for EEG pattern recognition
— build up library of trained mental commands
— use Emotiv API to map commands into controls in Unity, e.g. control virtual electrical wheelchair (manual mode) and menu system (autopilot mode)
— learn four basic EEG commands in Emotive training software: push, left, right, pull
— map basic commands to Unity controls dependent on mode

<table>
<thead>
<tr>
<th>command</th>
<th>manual</th>
<th>autopilot</th>
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</thead>
<tbody>
<tr>
<td>push</td>
<td>forward</td>
<td>choose</td>
</tr>
<tr>
<td>left</td>
<td>rotateLeft</td>
<td>down</td>
</tr>
<tr>
<td>right</td>
<td>rotateRight</td>
<td>up</td>
</tr>
<tr>
<td>pull</td>
<td>toggle</td>
<td>toggle</td>
</tr>
</tbody>
</table>
Manual and autopilot modes

— manual mode: EEG brain wave control of virtual electrical wheelchair

— autopilot mode:
  • user sets a target geographical location
  • a list of predefined locations is stored in the system
  • A* algorithm finds shortest path
  • wheelchair moves to target location in safe manner and avoiding obstacles

— only four brain control commands pose a challenge for navigating menus and switching modes

— employ “music player-like” navigation
  • scroll up and down a list of options
  • choose item or submenu
  • return to previous menu or switch mode with toggle
Preliminary artificial neural network (ANN)

— Emotiv EEG pattern recognition is advanced and powerful . . .
— . . . but proprietary and closed source code
  ⇒ motivates examining own, custom ANN
— designed simple experiment for preliminary ANN
  • classify two types of EEG states: *meditation* and *push*
  • employ Matlab Neural Network Toolbox
  • collect 200 raw EEG samples (10 sec) with these two states
    (training set: 140, validation set: 30, test set: 30)
  • 7 EEG channels $\times$ 6 frequency bands = 42 inputs
  • 21 neurons in hidden layer
  • two output classification states
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Game-based learning framework

Two main components:

- Emotiv EPOC EEG headset
- Unity 3D game engine
Summary of results

— large and realistic urban 3D virtual world
— five incrementally more difficult game levels for game-based learning and practicing of brain control of the wheelchair
— no paraplegic patients have tested the system
— three young and healthy participants are able to successfully use and complete all five game levels
— autopilot works as intended for five predefined locations
— safety measures: collision avoidance and rolling protection
— ANN successfully classifies meditation and push EEG states with 0–4% error rate
— proposed framework is low-cost, uses COTS equipment, and is easily extendable, flexible, and adaptable
Level 1

Learning/practice of single command (‘forward’) in drag race
Level 2

Switching of commands while navigating in labyrinth
Level 3

Learning to handle safety mechanisms
Level 4

Difficult/advanced tasks for improving navigation skills
Level 5

Integrated tasks in realistic real-world urban navigation
Example scatter plot for ANN classification
Future work

— safety issues extremely important and difficult in dynamic uncertain real-world environment
  • collision avoidance and rolling protection be refined and made more robust
  • add emergency interruption/override for “bad” user control input and in autopilot mode
  • a cue-based (synchronous) semiautonomous mode, where system helps user by guessing next action and provides suitable cue
  • add steady-state visually evoked potential (SSVEP) stimuli for more reliable control signals
  • use artificial intelligence (AI) for the above
— reverse-engineer closed source Emotiv software for custom needs
— better adaptability to user progression
— use framework for virtual prototyping of custom-made electrical wheelchairs designed for EEG brain control
— cooperate with medical staff and patients to improve framework and perform clinical trial
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blog.hials.no/softice
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References


Thank you for listening!

Questions?