Motivation System Analysis

Milestone 3 | Neurotech Controls for Motivational Framework (DFR5)

Milestone 3 description, verbatim from accepted project proposal:

➢ Functionality coding, use case exploration

a. **Description**: Based on the discoveries and outcomes of previous milestones, BCI functionality will begin to be coded to modulate the relevant motivational features. This is indicative of initial progress that would be towards a prototype functionality (in the subsequent milestone). The modulatable motivational features are middle-layer “levers” between the brain and Hyperon. Functionalities may be covered that are outside the bounds of the previously found motivational and brain features, if new ones have been identified since the previous milestones.

b. **Deliverables**:
1. Evidence of coding/programming progress on connecting the neurotech device to motivational features in order to modulate them.
2. Optional: Viable use cases selected (target=2 use cases), with evidence of additional (at least preliminary) coding demonstrating application toward use cases. Optional due to the dependency on progress of Deliverable #1.

c. **Success Criteria:** Coding has commenced and is underway to program relevant functionality of a BCI.

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Summary

In Milestone 3, the project has made significant strides in developing a Brain-Computer Interface (BCI) framework to modulate motivational features using real-time EEG signals. The **Offline Layer** is complete, with a trained deep regression model (EmotionNet) predicting continuous valence and arousal values, exported as a lightweight ONNX file. The **Online Layer** is nearly finalized, successfully streaming and processing EEG data via Lab Streaming Layer (LSL) and outputting predictions through WebSocket to Unity, tested with simulated signals. A use case, **Unity Virtual Character Facial Expression**, demonstrates coding progress by mapping emotional states to avatar animations. Despite challenges with model accuracy and device consistency, coding is actively underway, meeting the success criteria for Milestone 3.

GitHub is available here:
https://github.com/YangyulinAi/Neurotech-Controls-for-AGI-Motivational-Framework

Slide presentation is available here:
Neurotech Controls Project Prototype Milestone 3 (5-10).pdf

Project Overview

The project aims to create a BCI framework that links human emotional and cognitive states—specifically valence (pleasure) and arousal (activation)—to Artificial General Intelligence (AGI) motivational systems, such as those in SingularityNET's Hyperon. By mapping real-time EEG signals to these parameters, the system enables dynamic modulation of AI behavior based on human brain activity. This flexible framework supports applications like virtual characters, conversational agents, and embodied robotics without requiring backend modifications.

Building on Milestone 1 (motivational feature identification) and Milestone 2 (brain signal mapping), Milestone 3 focuses on coding functionality and exploring use cases. The architecture comprises three layers:

1. **Offline Layer**: Processes labeled EEG data, extracts features, and trains a model for valence and arousal prediction.
2. **Online Layer**: Streams live EEG data, applies real-time processing, and outputs predictions via WebSocket. [GitHub]
3. **Interface Layer**: Distributes predictions in JSON format for plug-and-play integration with applications.

Functionality Coding Progress

This section details the coding efforts to connect neurotech devices to motivational features, fulfilling the primary deliverable of Milestone 3.

Offline Layer Development

The Offline Layer processes existing EEG datasets to train a model for predicting valence and arousal. Key achievements include:

- **Data Preprocessing**: Two collected datasets were cleaned and segmented into 3-second windows with a 2.5-second stride.
- **Feature Extraction**: Two feature blocks were extracted:
    - Log-spectrogram tensors (1-40 Hz) for a convolutional neural network (CNN).
    - A 26-dimensional handcrafted vector, including Frontal Alpha Asymmetry (FAA), band-specific differential entropy, and AF7-AF8 alpha ratio.
- **Model Training**: A hybrid CNN-TCN (Temporal Convolutional Network) regression model, **EmotionNet**, was trained on a GPU with extensive hyperparameter tuning. It predicts continuous valence and arousal values.
- **Model Export**: The trained model was pruned and exported as a lightweight ONNX file (emotion_va.onnx) for deployment.

The Offline Layer is fully operational, providing a robust foundation for real-time inference.

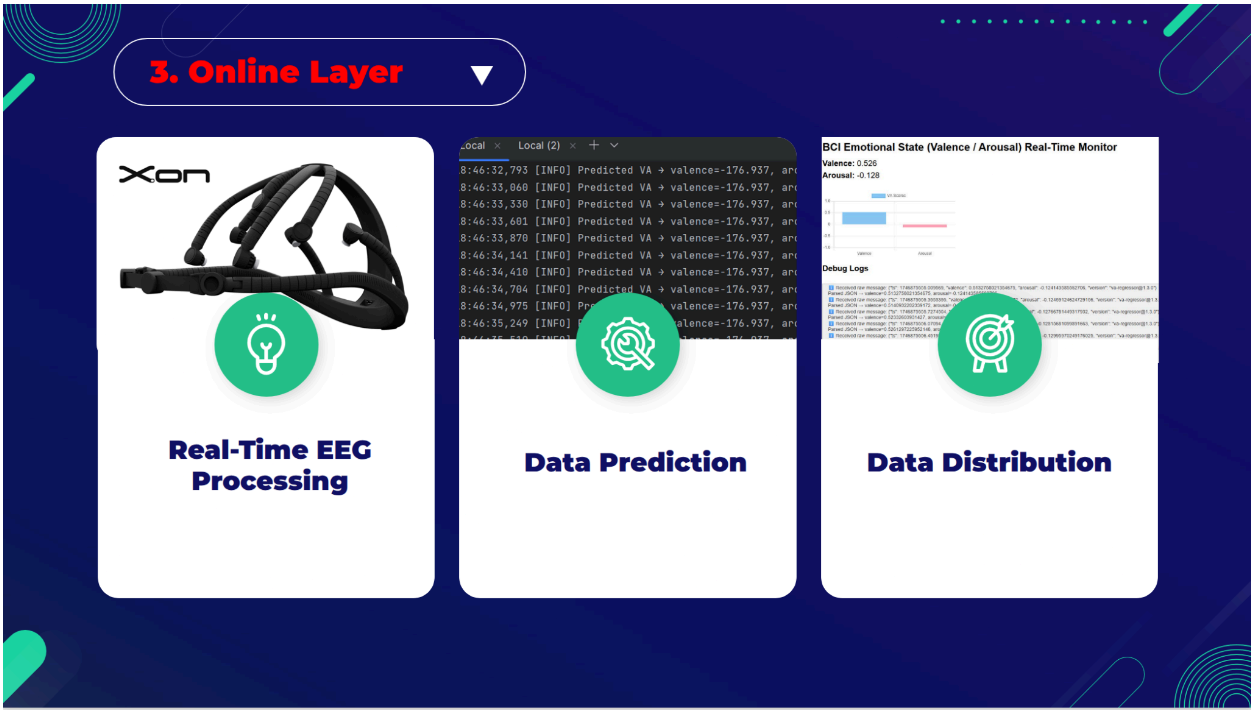
Online Layer Development

The Online Layer processes live EEG signals and delivers real-time predictions. Key developments include:

- **Data Acquisition**: EEG signals are streamed via LSL to a Python-based backend, initially tested with simulated data and later with the X.On EEG device.
- **Real-Time Processing**: The preprocessing pipeline mirrors the Offline Layer, ensuring consistency. The ONNX model performs inference with a latency of approximately 3 ms.
- **Data Distribution**: Valence and arousal predictions are transmitted via WebSocket to client applications, such as Unity, in JSON format.

The Online Layer is nearly complete, with stable outputs demonstrated using simulated signals. Testing with real EEG data from the X.On device revealed constant prediction values due to unoptimized electrode impedance, an issue slated for resolution.

GitHub:
https://github.com/YangyulinAi/Neurotech-Controls-for-AGI-Motivational-Framework/tree/main/Online%20Model



Use Case Exploration

The optional deliverable of selecting and coding a use case has been addressed with the **Unity Virtual Character Facial Expression** prototype, demonstrating the system's potential.

Unity Virtual Character Facial Expression

This use case modulates a virtual character's facial expressions based on real-time EEG-derived emotional states. The implementation includes:

- **Workflow**: EEG signals are processed to predict valence and arousal, currently classified into discrete emotions (Happy, Angry, Sad) by an **Emotion Controller** using rule-based thresholds, and mapped to avatar animations via a **Character Controller** in Unity.
- **Asset**: The "Cute Animal Party" 2D Unity asset was used as a placeholder, featuring pre-rigged animations for Happy, Angry, and Sad. Three public methods—Happy(float duration), Angry(float duration), and Sad(float duration)—enable seamless emotion switching.
- **Pipeline**: The end-to-end flow (Python → WebSocket → Unity → Facial Expression) updates within seconds, verified through an early demo.

While the current asset's expressiveness is limited (head tilt and overlay effects), it confirms the pipeline's integrity. Plans to upgrade to 3D assets with full facial animations are underway.

Challenges and Future Plans

Several challenges emerged during Milestone 3, which we endeavor to sufficiently address by project completion:

- **Model Accuracy**: Limited training data and device inconsistency (NeuralScan Curry 8 laboratory-grade system for training, X.On for testing) resulted in suboptimal classification accuracy.
- **Device Issues**: Unoptimized electrode impedance with the X.On device caused constant prediction values in real-time tests.
- **Asset Limitations**: The placeholder 2D asset lacks the expressiveness needed for a polished demo.

Future plans include:

- **Data Collection**: A test session is scheduled to collect additional EEG data using the X.On device, aligning training and testing datasets.
- **Model Optimization**: Refine training parameters and hyperparameters to enhance prediction accuracy.
- **Asset Upgrade**: Source or create 3D assets with culturally recognizable facial animations for improved expressiveness.

Discussion and Implications

The successful development of the Offline and Online Layers demonstrates significant progress in coding BCI functionality to modulate motivational features. The use case highlights the framework's potential to translate brain signals into tangible AI behaviors, aligning with the project's goal of human-AI co-creation. While discrete emotions were used for clarity, the continuous valence and arousal outputs offer flexibility for future applications.

The challenges underscore the need for robust data and device consistency, critical for scaling the system. Addressing these will strengthen the framework's reliability and broaden its applicability across domains like healthcare, gaming, and robotics.

GitHub

Experiment GitHub repository:
https://github.com/YangyulinAi/Neurotech-Controls-for-AGI-Motivational-Framework

Online Layer:
https://github.com/YangyulinAi/Neurotech-Controls-for-AGI-Motivational-Framework/tree/main/Online%20Model