P300 Speller Notes

1 Info on P300 Speller

A P300 speller consists of 36 alphanumeric characters arranged in a 6x6 matrix. The user has to focus their attention on a character, and then rows and columns will flash in a random sequence. There are many different variations to the P300 paradigm that aim to improve this framework. In the classical variation, a sequence of 12 different flashes (6 rows and 6 columns) is called an iteration. These flashes form an oddball paradigm, with two different types of stimuli: target and non-target, occurring at frequencies of 0.166 and 0.833, respectively. The target response, which is more rare, should elicit the P300 response; in this case, the target stimulus is the row/column containing the desired character.

A classification algorithm is needed to distinguish between these stimuli. In ERP-based BCIs, many iterations are required to improve the SNR (signal-to-noise ratio) for accurate selection. Machine learning and optimization techniques can further improve classification performance.

2 Optimizations of a P300-Based BCI Speller

Brain-computer interface (BCI) spellers enable communication for severely motor-disabled patients using brain activity without muscular mobility. Several usability factors of the speller, such as size and visual configurations, have been studied extensively. Key findings include:

- **Speller Size Comparison**: - Evaluated two matrix sizes: 3x3 and 6x6. - Found medium-sized spellers had lower error rates (EP = 25%) but no significant differences among sizes. - Small size spellers resulted in higher physical demands and lower satisfaction. - Large size spellers caused visual and spatial challenges.
- **Adaptive Stimulus Selection**: - Focused on enhancing stimulus presentation efficiency by using a data-driven method that adaptively selects stimuli. - Maximized the P300 response by concentrating on characters with higher uncertainty in classification. - Improved accuracy, especially in dynamic environments where user performance varies significantly over time.

- **Visual Factors Evaluation**: - Analyzed how speller size, symbol spacing, and matrix design affect performance. - Concluded that medium-sized spellers (9.98 cm with 0.75°H × 0.75°W symbol size and 1° spacing) are the best for general usability. - While medium size is optimal for motor-disabled users, large spellers may be suitable for users with higher mobility or when higher character density is needed.

3 Links to EEG Data for P300 Speller Brain-Computer Interfaces

- `https://www.nature.com/articles/s41597-022-01509-w#ref-CR28`
- `https://www.bbci.de/competition/iii/desc_II.pdf`

4 Data Obtained from BCI Competition III (Link 2)

The recorded data from the competition dataset is organized into four `.mat` files: one training file (85 characters) and one test file (100 characters) for each of the two subjects (A and B). All data is stored in single precision and may need to be converted to double precision. For each file, the recorded 64-channel EEG signal is organized in a matrix (stored as `Signal`).

Note: Since the subjects had to spell actual words in each run, the character epochs are scrambled in the training and test sets to prevent identification of the correct test set characters by the participants.

Each sample in the `Signal` matrix has associated event codes, defined by these variables:

- **Flashing**: 1 when a row/column was intensified, 0 otherwise.
- **StimulusCode**: 0 when no row/column is being intensified (matrix is blank), 1-6 for intensified columns, and 7-12 for intensified rows.
- **StimulusType**: 0 when no row/column is being intensified or when the intensified row/column doesn't contain the desired character, and 1 when the intensified row/column contains the desired character. This variable provides labels in the training sets, separating responses that contained the desired character from those that did not.
- **TargetChar**: The correct character label for each character epoch in the training data.

5 Steps to Extract the Signal Waveforms Associated with the Intensification of a Particular Row/Column

1. For one or more channels, collect a period of signal samples at the start of each intensification, i.e., whenever `Flashing` changes from 0 to 1. (Note: each character epoch of the dataset starts at the first flash, so `Flashing` = 1 for the first data sample in each epoch.)
2. Accumulate the signal samples in 12 separate buffers, using the `StimulusCode` for the corresponding stimulus. For each character epoch, each buffer should contain the 15 sample periods, one for each intensification of the given row/column.

6 References

- Bianchi, L., Liti, C., Liuzzi, G., et al. Improving P300 Speller performance by means of optimization and machine learning. *Annals of Operations Research, 312*, 1221–1259 (2022). `https://doi.org/10.1007/s10479-020-03921-0`
- `https://www.frontiersin.org/journals/human-neuroscience/articles/10.3389/fnhum.2020.583358/full`
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