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Enhancing Brain-Computer Interface Algorithms and Feedback: Implications for Use in Post-stroke Rehabilitation

By

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Presentation outline

- Our research group and RTD facilities
- BCI approach
- BCI and Mental Practice-based post-stroke rehabilitation
- Research objectives
- Algorithmic enhancements
- Some experimental results
- Implication for use in Rehabilitation
- Further research work

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Our Research Group

- We are part of a recently launched £20M centre of excellence in Intelligent Systems with core activities in:
  - Software and hardware implementations of neural networks, fuzzy systems, and GAs
  - Bio-inspired Intelligent Systems – Brain Modeling
  - Brain computer Interfacing (BCI)
  - Intelligent Robotics
  - Embedded systems
  - Re-configurable computing/FPGA systems
  - Multiple valued logic systems
  - Machine vision
  - Intelligent process control
- BCI laboratory facilities:
  - A state-of-art BCI experimental setup with 56 EEG channels, 8 EMG channels
  - An 8 EEG/EMG channel mobile unit
  - A 4 EEG channel wireless mobile unit
  - EMF screened room
  - Multiple electrode systems

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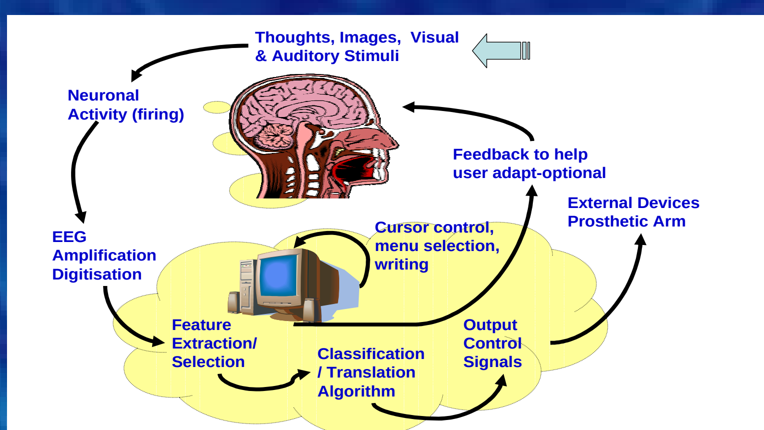
EEG-based BCI



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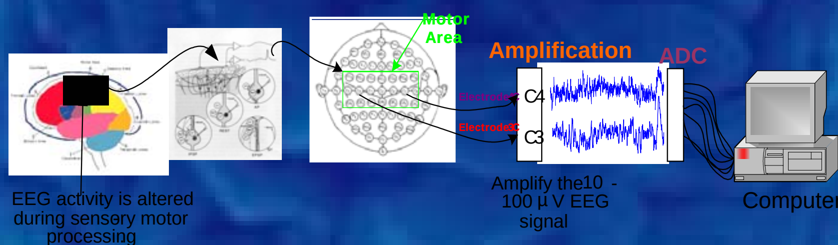
Our approach to EEG-based BCI…



- **Mental Tasks (e.g. imagination of right and left hand movement)**
- **Lateralisation – contralateral-ipsilateral differences**
- **µ (8-12Hz) and central ß (18-25Hz) undergo event related desynchronisation / synchronisation (ERD / ERS)**
  - **signal amplitude attenuation and enhancement phenomena**

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BCI and Mental Practice (MP) for post-stroke rehabilitation

- Annually over 20M people suffer from stroke world-wide and 30% to 60% of 80% survivor are unable to use their affected arm;
- In MP-based rehab, subjects perform repetitive MP of routine motor tasks (i.e. motor imagery) on regular intervals[1];
- Significant improvement in upper limb recovery is reported if MP is undertaken alone or along with physical practice;
- The hypothesis is use-dependent brain-reorganisation, i.e. new cortical areas are recruited.
- However, all subjects may not benefit due to lack of sufficient focus and motivation and are selected based mini mental status examination (MMSE);
- Also, currently MP is undertaken under professional support only, which is expensive;
- Through BCI, appropriate feedback of actual occurrence of MP may enhance rehab effectiveness and motivate less focussed subjects.

- Crosbie, JH, McDonough, SM. The Adjunctive Role of Mental Practice in the Rehabilitation of Upper Limb after Hemiplegic Stroke: A Pilot Study. Clinical Rehabilitation 18: 60-68, 2004.

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Research Challenges

- Continuous but robust adaptation of BCI system to account for ever-changing brainwave characteristics due to mental fatigue etc;
- Robust handling of uncertainty in EEG due to non-stationary brain dynamics and varying noise characteristics of measurement environment;
- Designing applications despite less than 100% accuracy, e.g. providing correct feedback about motor imagery during rehabilitation tasks.

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Our BCI Research

- Main BCI research objectives:
  - To devise a robust BCI system that can self-organise and adapt to each individual's EEG autonomously and to the inherent day-to-day changes
  - To effectively account for uncertainties inherently present in EEG due to non-stationary brain dynamics and varying noise characteristics of the measurement environment.
  - To devise effective applications for improving quality of life as well as rehabilitation purposes.
- Research work Undertaken:
  - Time-series prediction approach for pre-processing and feature extraction
  - Comprehensive and conclusive analysis of best spectral approaches to feature extraction
  - Type-2 fuzzy logic (T2FL) approach for classifier design
  - Design of appropriate feedback
  - A self-organising non-parametric BCI
  - Real-time implementation and extensive experimental evaluation on healthy subjects over several months with the objective of creating an active post-stroke rehabilitation system

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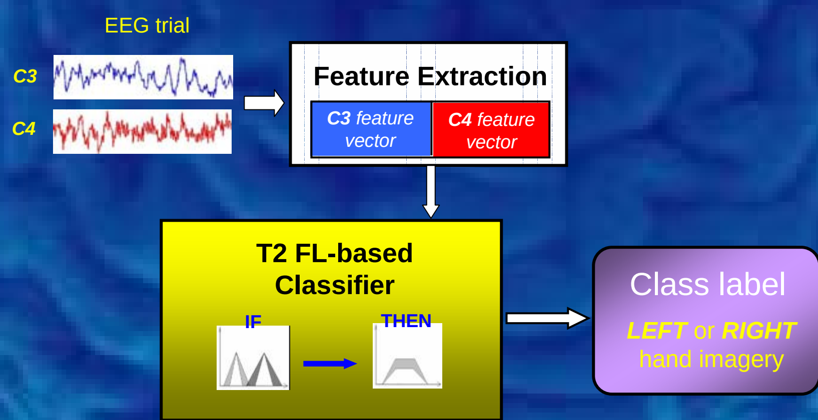
Type-2 Fuzzy Logic (T2FL)-based Robust Classifier



Type-2 Fuzzy Logic-based Methodology

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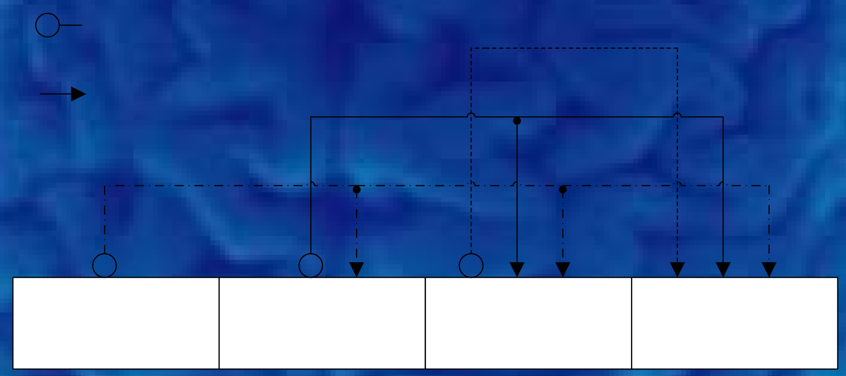
Design of T2FL Classifiers

1. Initial rule base identification
   - mapping-constrained agglomerative (MCA) clustering algorithm
   - An SVM-based approach for enhanced robustness
2. Parameter tuning phase
   - gradient descent algorithm
   - calculation of dynamical optimal learning rate for the consequent parameters

•Promising results: Significantly higher robustness and classification accuracy

Evaluating Classifier for Cross-session Performance



Illustrating the inter-session experimental design for four-session data:- Cat I:I-II, II-III, III-IV; Cat II:I-III; II-IV; Cat III:I-IV

Table I: Comparative analysis of classifiers in the multi-session experimental setup by averaging across 7 subjects

Classifier	**Training session**		**Test – cat. II**	**Test – cat. III**	**Test – cat. IV**
	mean CA ± std.dev. [%]				
	10 x 5-fold CV	*training*	*one-pass test*	*one-pass test*	*one-pass test*
T2 FLS	70.9 ± 9.0	75.4 ± 7.7	**73.2** ± 9.7	**62.2** ± 4.0	**63.1** ± 4.9
T1 FLS	69.8 ± 8.9	73.9 ± 7.9	71.4 ± 8.7	61.1 ± 4.3	61.4 ± 5.7
LDA	**71.2** ± 9.0	74.7 ± 9.1	67.2 ± 9.9	58.9 ± 6.2	57.4 ± 5.1
RFD	70.2 ± 7.4	72.5 ± 6.2	68.4 ± 9.5	58.8 ± 6.0	57.0 ± 5.2
SVM_{lin}	70.7 ± 9.9	73.7 ± 8.4	69.8 ± 9.6	58.2 ± 6.7	55.7 ± 5.0
SVM_{Gauss}	70.5 ± 9.9	**75.7** ± 7.0	69.7 ± 9.5	59.2 ± 6.1	57.4 ± 5.9

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Comparative Evaluation of Different Feedbacks

- Cognitive Tasks:
  - Kinaesthetic motor imagery of ball clenching in left or right hand.
- Feedback types
  - No feedback
  - Simple feedback: directional cue
  - Game-like feedback: Basket paradigm

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Subject S7: Feature Seperability

Session→ / Feature type↓	es2	es3	es4	es7	es8	es9	es10	es11
STFT	68.5	67.3	69.8	68.6	69.7	66.4	68.3	69.2
STFT_Nvec	71.1	72.9	72.9	70.8	71.1	65.6	68.0	72.3
PSD_PERIOD	69.3	67.2	70.1	68.9	69.2	66.4	67.6	69.8
PSD_PERIOD_Nvec	70.6	71.8	67.4	69.6	72.0	68.7	67.5	72.3
PSD_ARYULE	69.6	71.3	68.9	69.5	69.1	68.8	68.4	74.7
PSD_ARYULE_Nvec	**69.0**	**70.0**	**68.3**	**69.3**	**71.9**	**72.1**	**68.8**	**75.8**

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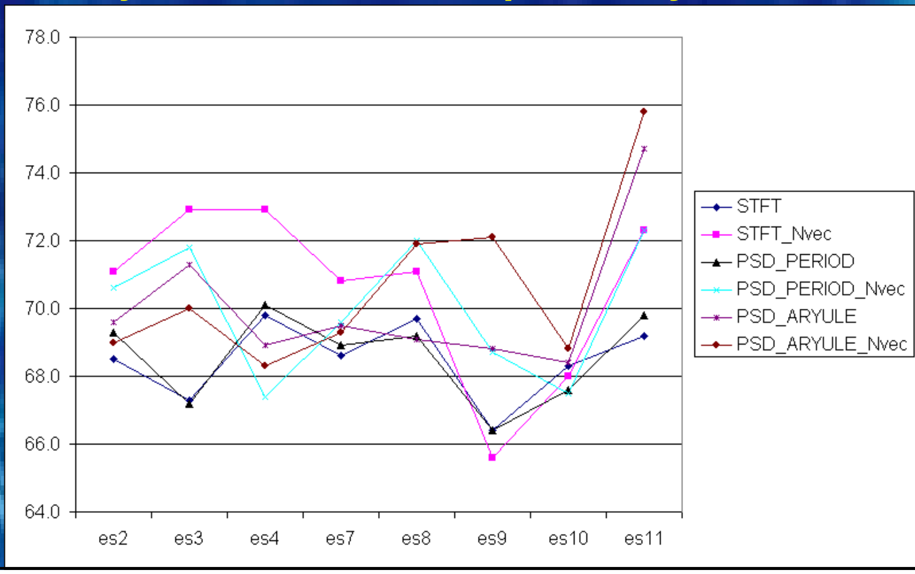
Subject S7: Feature Separability….



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Subject S12: Feature Separability

Session→ Feature type↓	es2	es3	es7	es8	es9	es10	es11
STFT	71.8	68.6	72.4	70.7	72.9	69.3	73.1
STFT_Nvec	72.9	67.4	71.8	71.3	73.7	68.4	73.3
PSD_PERIOD	71.4	67.5	71.3	70.5	72.2	68.5	71.2
PSD_PERIOD_Nvec	73.1	67.6	71.7	71.6	73.8	68.7	73.4
PSD_ARYULE	72.8	70.7	77.3	77.5	79.4	79.7	77.1
PSD_ARYULE_Nvec	**74.6**	**71.1**	**77.8**	**77.8**	**79.5**	**84.6**	**79.4**

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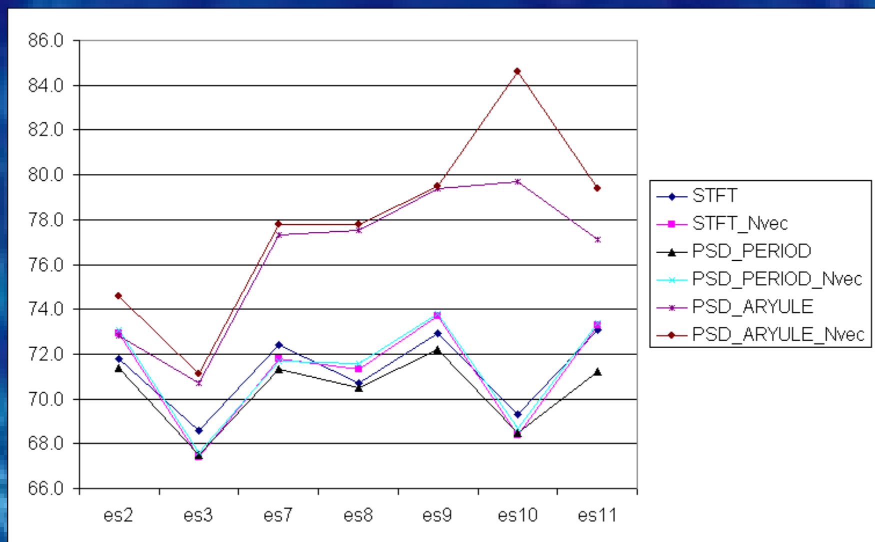
Subject S12: Feature Seperability…



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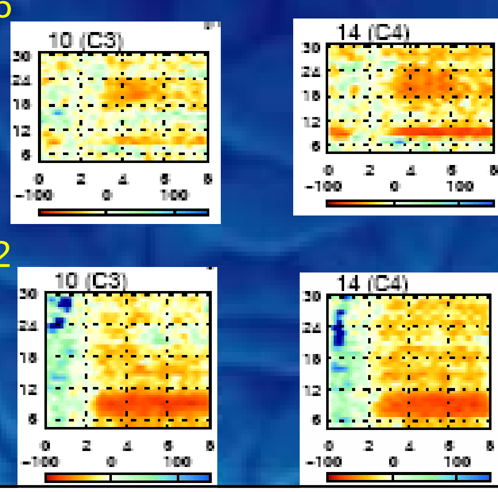
Cortical changes: ERDMAPS during left hand movement in S12

Session 6

Session 12



red ERD
blue ERS

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Implication for use in Rehabilitation

- Subjects appeared more enthusiastic with game-like feedback. Motivation appears to have been enhanced qualitatively.
- Increase in separability (i.e. detection accuracy) is however less significant during limited number of training sessions.
- Over time with repeated MI practice, feature separability does increase even for subjects that initially show poor MI performance.
- Investigation is needed to ascertain the effect of less than 100% accurate neuro-feedback.

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Further Research Work

- Advanced modelling approaches for improving feature separability;
- Self-adaptive Brain-Computer Interface;
- Enhancing mental practice through BCI-based neuro-feedback for post stroke rehabilitation in collaboration with Health and Rehabilitation Sciences Research Institute
  - Ethical approval is awaited for trials on disabled subjects;
  - Long-term controlled trials are planned;
  - Designing of enhanced feedback

Conclusions

- Robustness, uncertainty handling, and adaptability are key challenges.
- Our TSP approach as an EEG data preprocessing procedure significantly enhances effectiveness of feature extraction procedures.
- T2FLS based classification approach shows potential in more effective handling of signal variability and uncertainty.
- Through BCI, appropriate feedback of actual occurrence of MP may enhance MP-based post-stroke rehab effectiveness and motivate less focussed subjects.
- Further algorithmic enhancement is needed for developing a practical BCI.
- Randomised controlled trial on disabled subjects needs to be conducted. Further enhancement in feedback design may be needed .

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Questions

Thank you