Developing a 3- to 6-state slow cortical potentials Brain-Computer Interface for high performance control of a 3D robotic manipulator

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BCI

Neural/Brain-Computer Interfaces are systems that directly interface with the nervous system and by that provide possibilities for immediate neural control of and communication with computerized and robotic devices

BCI

- fMRI
- Embedded Electrodes
- Microelectrode Arrrays
- ECoG (corticography)
- EEG (encephalography)
- EMG (myography)

- Speller (text entry)
- Computer Interface (mouse movement, email, browsing)
- BCI Wheelchairs (robotic)
- Manipulator SystemS (robotic)
- Hand/Arm Prostheses (bionic)
- Exoskeletons (robotic)
- State Discovery and Monitoring (passive)

Imaging--

--Actuation

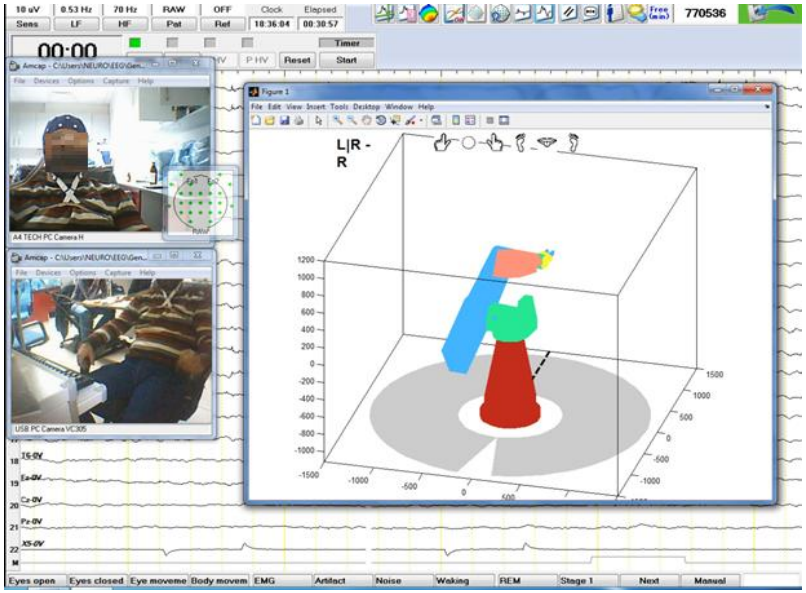
BCI

We develop BCI based on electroencephalo-graphic brain activity signal for control of a robotic manipulator arm

Signal Processing Station

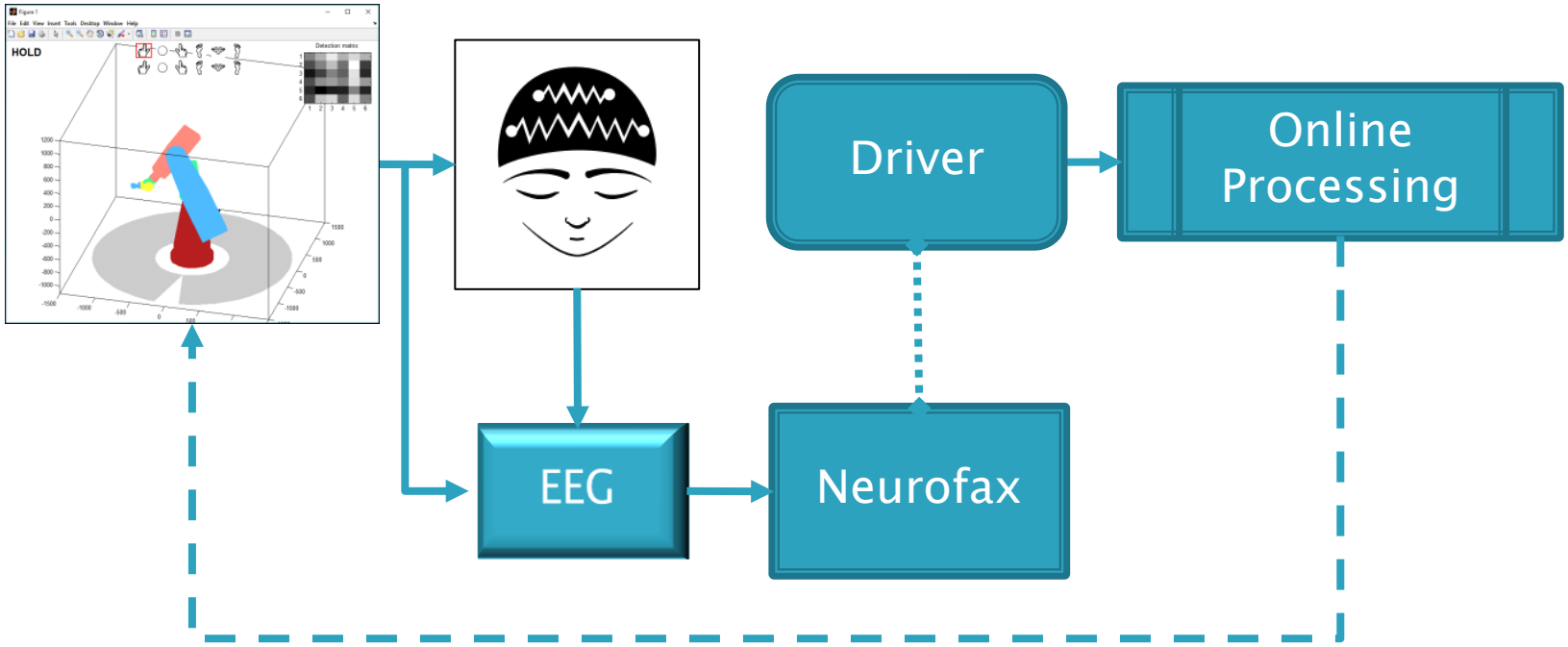
EEG Signal Acquisition Box

Control Simulated Puma3D Robotic Arm 3 dof



BCI

EEG brain computer interface for robotic arm control



BCI

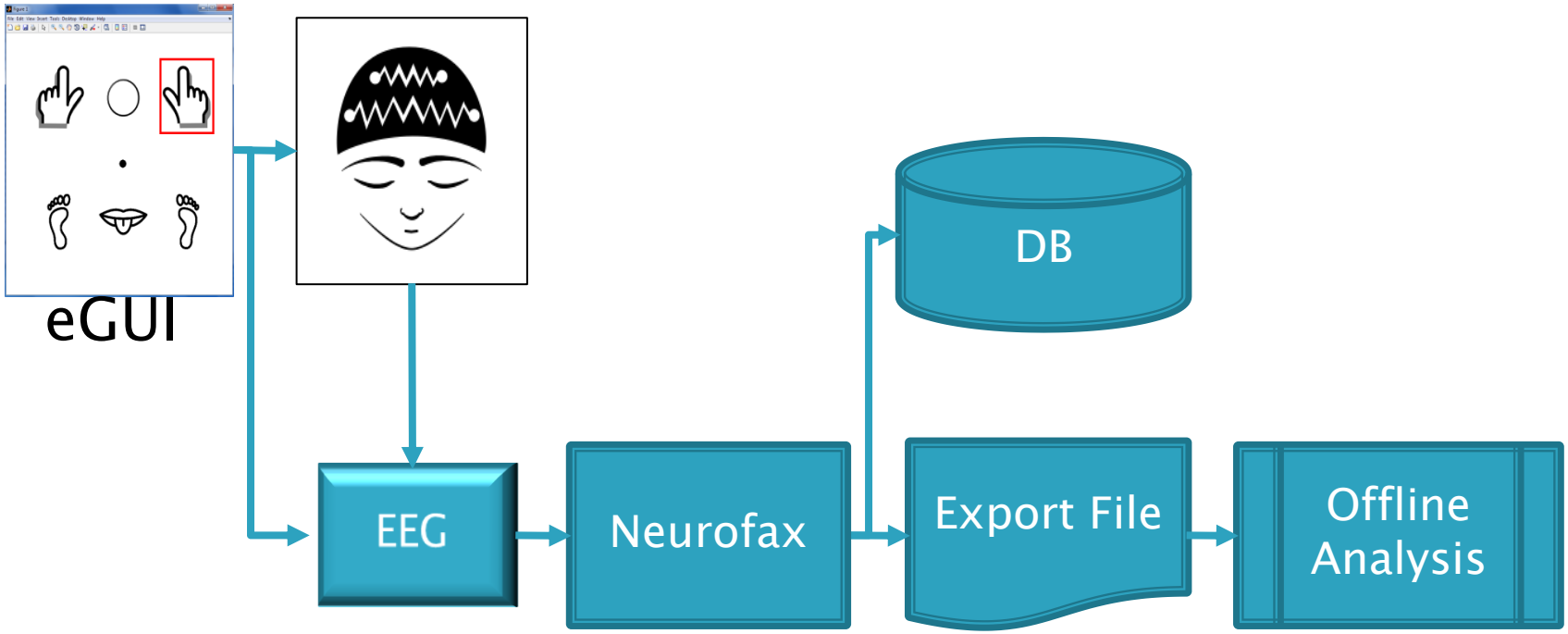
NIHON KOHDEN EEG-1200

- *medical grade EEG system*, 19-38 channels, 200-1000 Hz sampling rate, 0.01 μV voltage resolution

EMOTIV EPOC

- *portable EEG headset*, 12 channels, 128 Hz sampling rate, 0.5 μV voltage resolution, Bluetooth connection

Preliminary evaluations



Preliminary evaluations

Subject	Performance 2-State		
	Average	Worst	Best
BA	0.77	0.75	0.79
EM	0.96	0.93	1.00
ER	**0.95**	**0.89**	**0.99**
HI	**0.98**	**0.96**	**0.99**
ME	0.75	0.66	0.84
MR	0.88	0.74	0.92
SE	0.95	0.89	1.00
YU	0.91	0.78	0.93
EK	0.84	0.76	0.93
ES	**0.99**	**0.98**	**0.99**
UL	0.81	0.76	0.87
YL	**0.98**	**0.98**	**0.98**
Overall	**0.90**	**0.66**	**1.00**

Chance level: 0.50±0.04

Subject	Performance 3-State		
	Average	Worst	Best
BA	0.54	0.49	0.58
EM	0.85	0.80	0.89
ER	**0.89**	**0.83**	**0.93**
HI	**0.89**	**0.86**	**0.95**
ME	0.52	0.42	0.62
MR	0.70	0.59	0.82
SE	0.82	0.63	0.90
YU	0.76	0.71	0.83
EK	0.71	0.61	0.81
ES	**0.98**	**0.96**	**0.99**
UL	0.69	0.58	0.80
YL	**0.90**	**0.89**	**0.91**
Overall	**0.77**	**0.49**	**0.99**

Chance level: 0.33±0.04

Subject	Performance 6-State		
	Average	Worst	Best
BA	0.33	0.29	0.37
EM	0.74	0.69	0.80
ER	**0.79**	**0.70**	**0.86**
HI	**0.84**	**0.80**	**0.87**
ME	0.35	0.22	0.47
MR	0.49	0.37	0.61
SE	0.60	0.50	0.66
YU	0.62	0.55	0.70
EK	0.63	0.52	0.74
ES	**0.93**	**0.89**	**0.97**
UL	0.56	0.47	0.64
YL	**0.87**	**0.84**	**0.89**
Overall	**0.64**	**0.29**	**0.97**

Chance level: 0.17±0.03

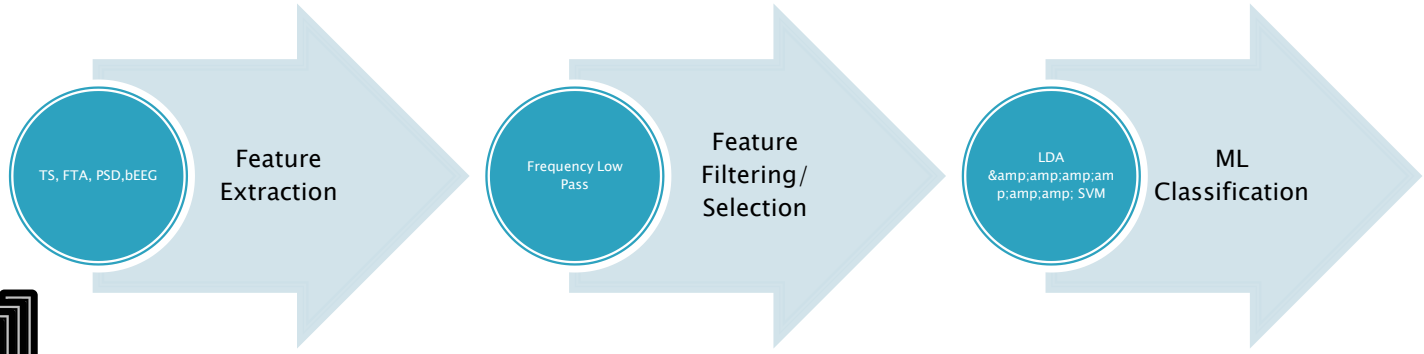
Preliminary evaluations

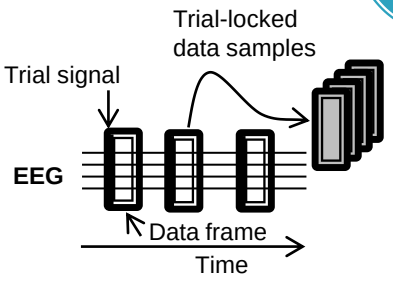
We have:

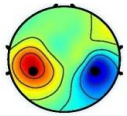
- For **2 states** – 7 subjects in 90–99%, 3 subjects in 80–90% and 2 subjects in 70–80% performance range
- For **3 states** – 5 subjects in 85–98%, 5 subjects in 75–85% and 2 subjects in 50–70% range
- For **6 states** – 4 subjects in 80–93%, 5 subjects in 50–80% and 3 subjects in 30–50% range

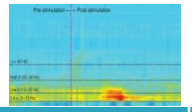
BCI Decoder Design

Data Processing Sequence:







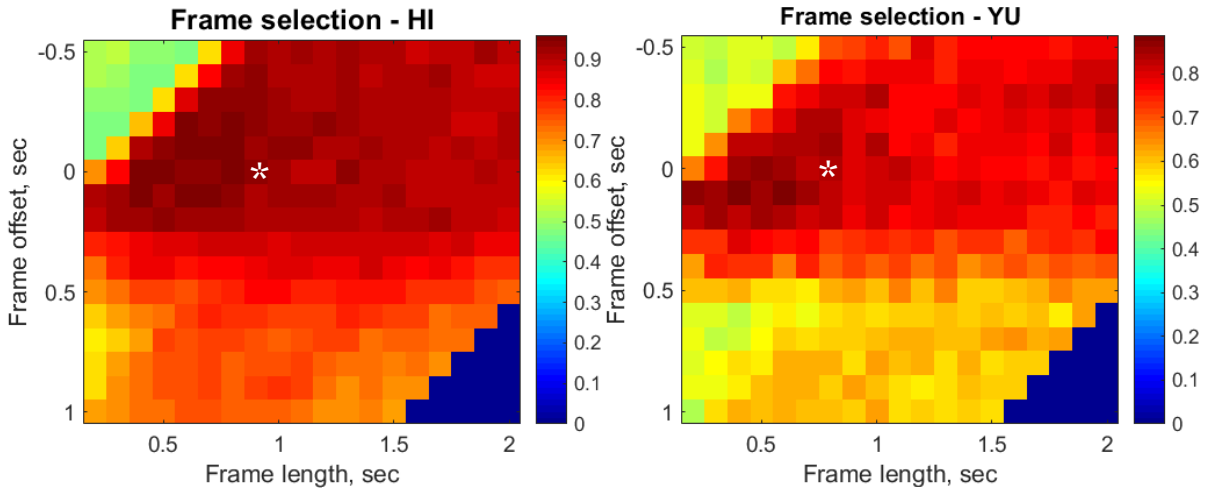


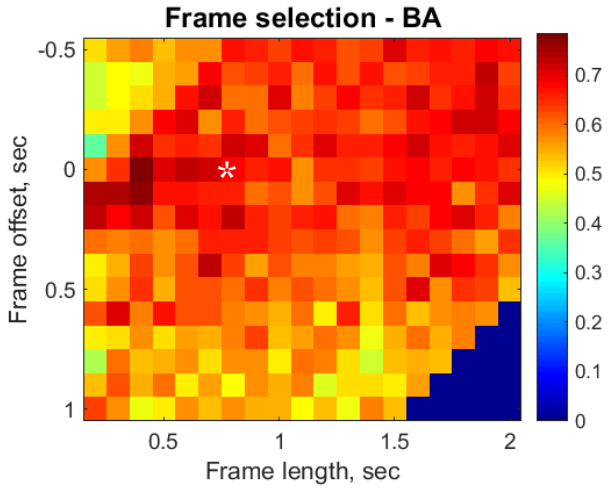
	bEEG*	bEEG dB	PSD*	PSD dB	FTA Polar*	FTA Cartesian	TS*
SVMx2	0.770	0.769	0.780	0.766	0.812	**0.910**	0.897
SVMx3	0.579	0.594	0.580	0.560	0.624	**0.744**	0.757
SVMx6	0.439	0.427	0.422	0.384	0.432	**0.594**	0.597
LDAx2	0.698	0.710	0.740	0.717	0.769	**0.860**	0.858
LDAx3	0.578	0.612	0.586	0.563	0.622	**0.754**	0.734
LDAx6	0.443	0.439	0.453	0.415	0.493	**0.646**	0.605

*bEEG – EEG band powers; PSD – power spectral density, FTA – Fourier Transform amplitudes, TS – time series

BCI Decoder Design

Data Frame Selection:

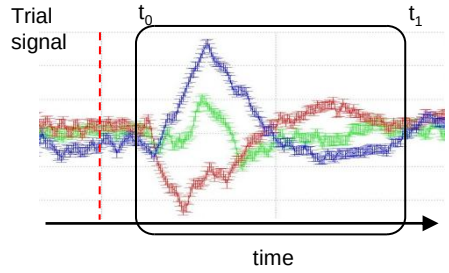




Best data frame:
[0 – 0.85] sec

Subject and run-specific adjustment of data frame can result in up to 5% performance gain !

Data Frame:



BCI Decoder Design

ML Classifier Selection:

	bEEG*	bEEG dB	PSD*	PSD dB	FTA Polar*	FTA Cartesian	TS*
SVMx2	0.770	0.769	0.780	0.766	0.812	0.910	0.897
SVMx3	0.579	0.594	0.580	0.560	0.624	0.744	0.757
SVMx6	0.439	0.427	0.422	0.384	0.432	0.594	0.597
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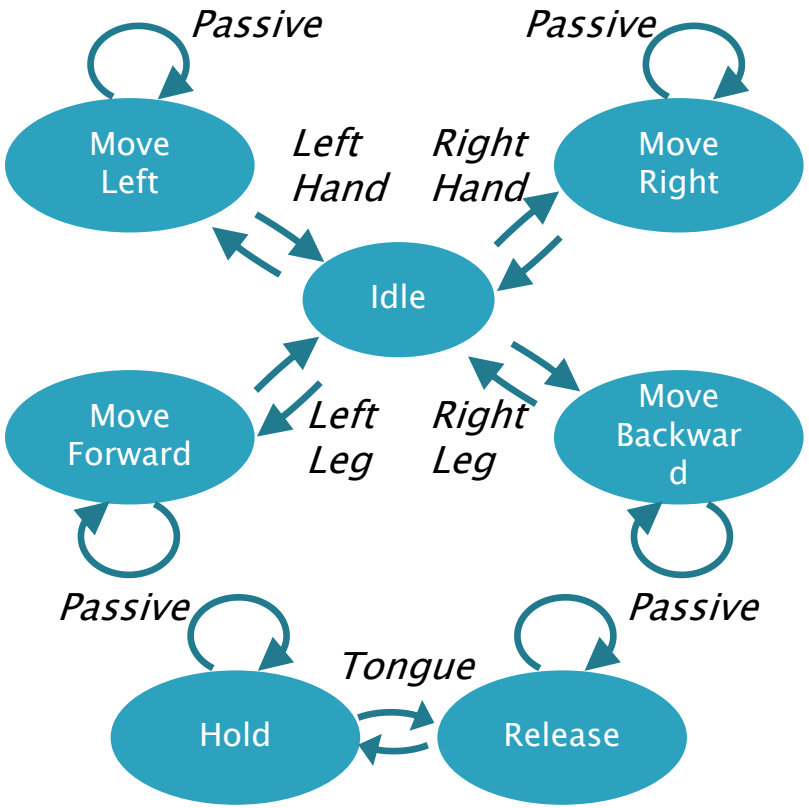
LDAx6	0.443	0.439	0.453	0.415	0.493	0.646	0.605

LDA and SVM perform nearly identically, with SVM outperforming slightly at low target counts and LDA performing slightly better at high target counts

BCI Interaction Protocol

Control protocol:

6-state 3 dof control protocol:

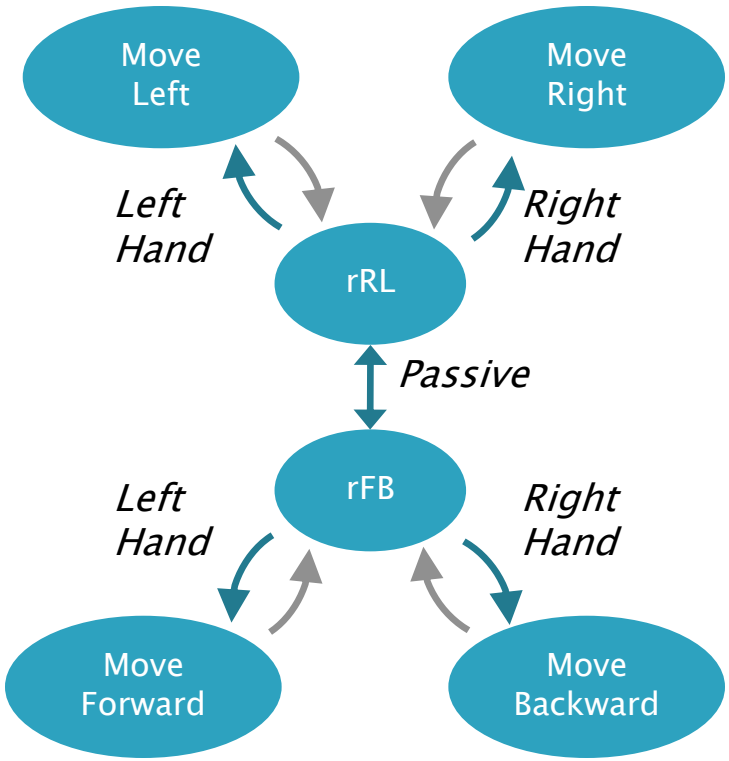


Expected performance: 2.6 bit per trial at 60% accuracy
approx 30 bpm

BCI Interaction Protocol

Control protocol:

3-state 2 dof control protocol (with state switching):

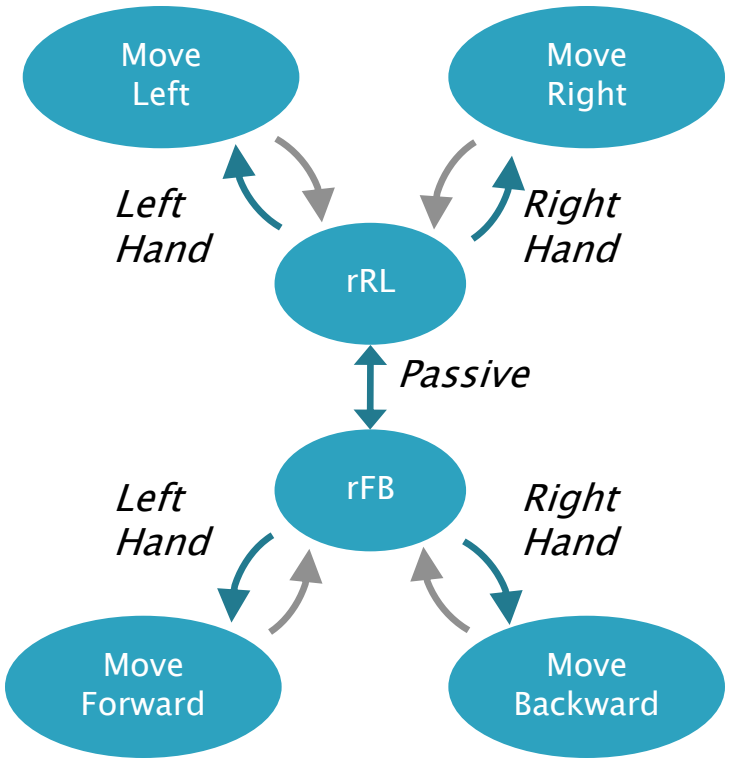


Expected performance: 1.6 bit per trial at 75% accuracy
approx 25 bpm

BCI Interaction Protocol

Control protocol:

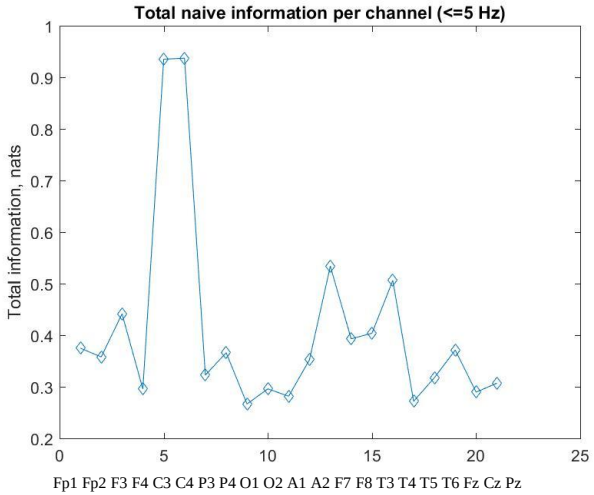
3-state 2 dof control protocol (with state switching):



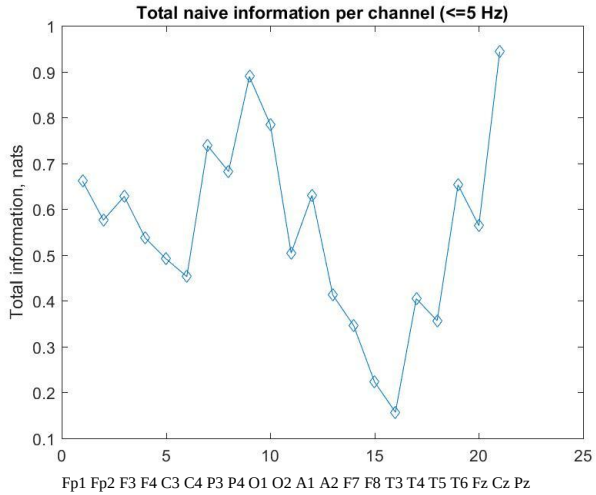
In practice we find this protocol to perform better in interactive experiments due to higher effective user self-confidence

Certain properties of EEG signal

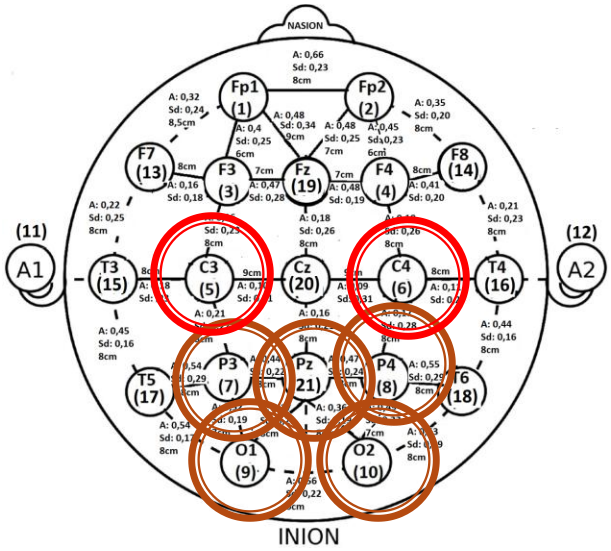
Naïve information per channel, 3 states



Naïve information per channel, 6 states

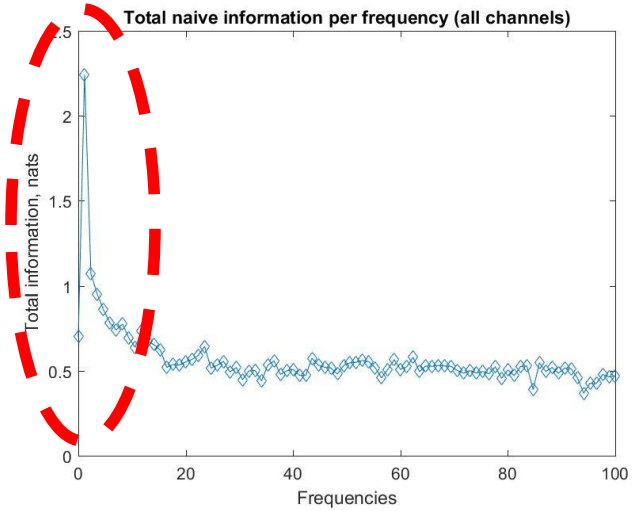


Most signal comes from parietal and occipital lobes (excludes EMG contaminations)

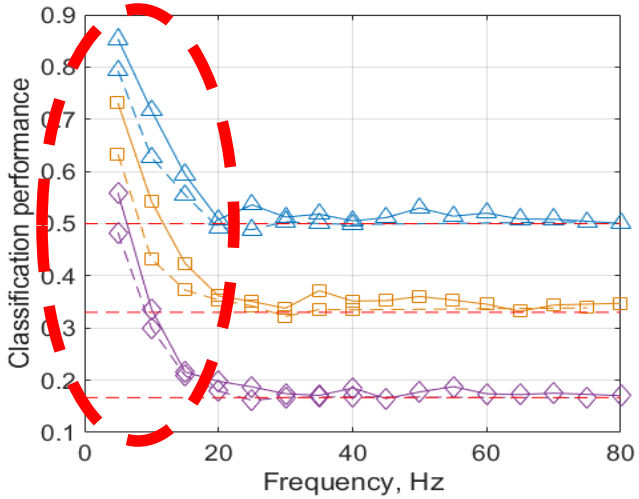


Certain properties of EEG signal

Naïve information per frequency



BCI decoder's performance vs. frequency range

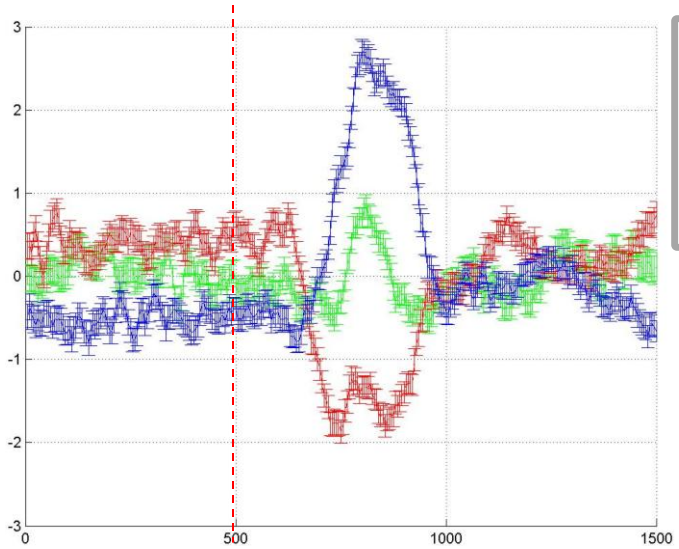


Low frequency oscillations in the range 0-5 Hz (at most 0-15 Hz) contribute the most to the mental (motor) imagery detection

Certain properties of EEG signal

Average EEG response (ERP):

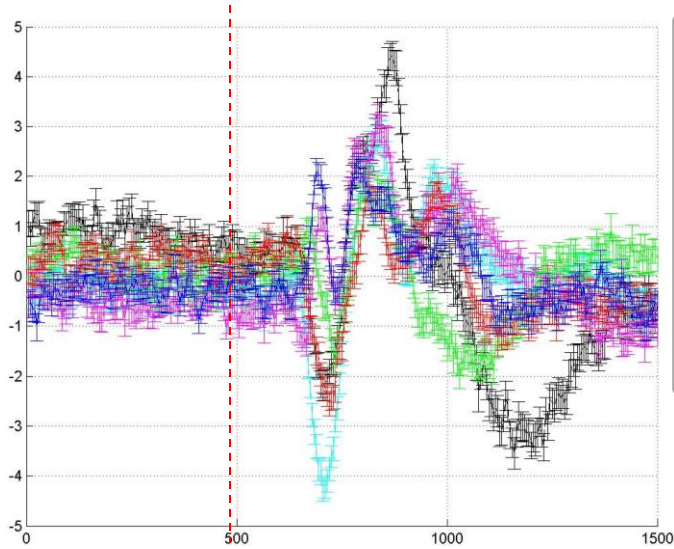
3-state



Right hand
Neutral
Left hand

"C3"

6-state



Right hand
Right leg
Neutral
Tongue
Left leg
Left hand

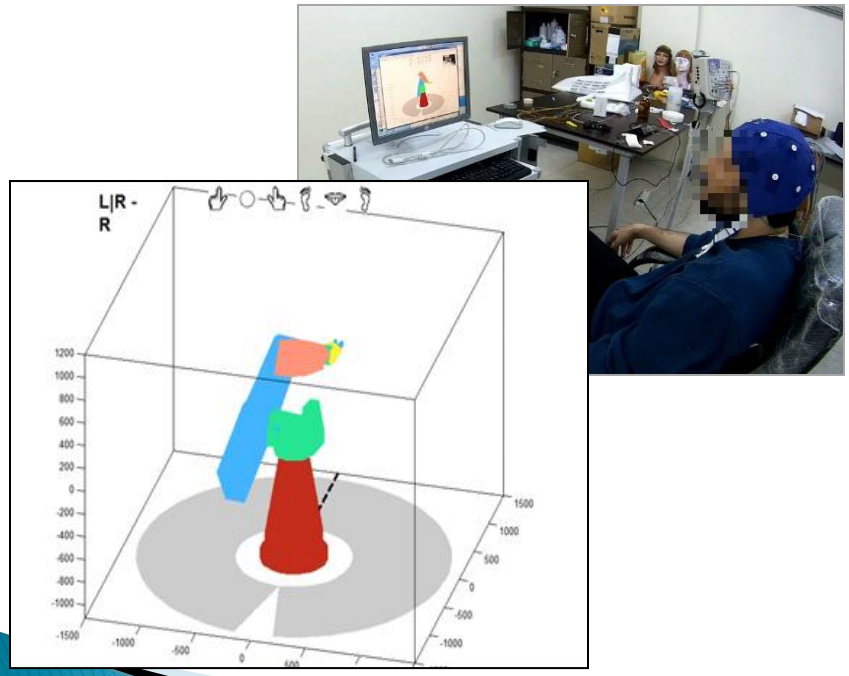
"P3"

Interactive Trialing

BCI decoder training – 15 min

Subject decoder exploration – 15 min

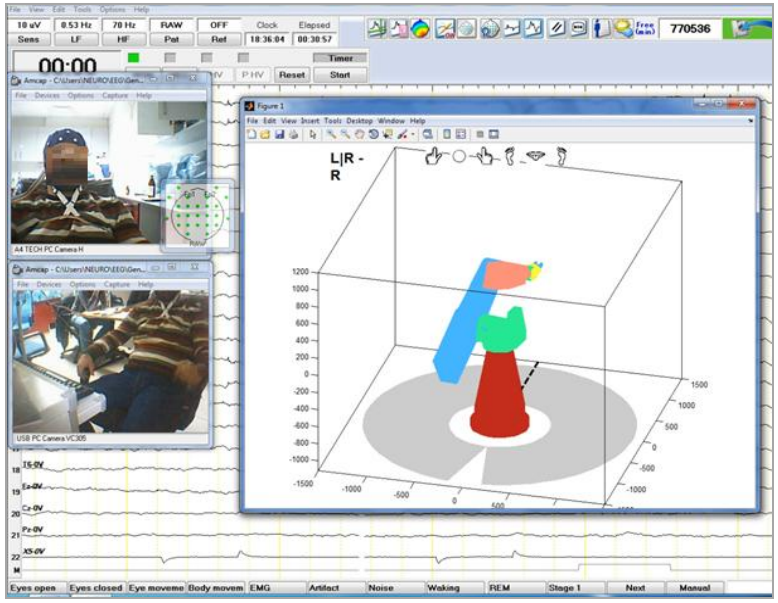
Test on verbal commands execution – 15 min



Test tasks: “move robotic arm 2 steps to left and 1 step forward”

Evaluated: (i) percentage of tasks completed; (ii) time taken to complete a task; (iii) percentage of correct manipulator moves towards the goal

Interactive Trialing



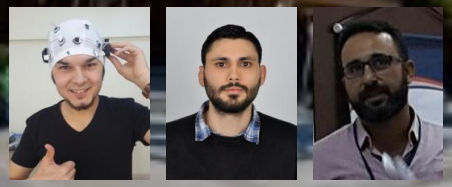
Subject	HI	ER	ES
Task completed	100%	100%	40%
Control accuracy	84.6%	77.6%	49.6%
Baseline time per move	4.1 sec	4.1 sec	4.1 sec
Time per move	6.5 sec	9.3 sec	26.7 sec

Conclusions

- Implemented EEG BCI for control of simulated 3D robotic arm
- Can distinguish up to 6 mental imagery states with 50-90% accuracy
- New features (FTA) boost mental imagery detection ability
- Adjustable selection of event data frames is important to further improve accuracy
- Protocol for BCI control is a key element of design and still needs significant analysis and tweaking to improve

Lab members:

- Murat Kaya
- Hilmi Yanar
- Erkan Ozbay



Funding:

- The Scientific and Technological Research Council of Turkey (TUBITAK) ARDEB Grant No 113E611
- The Science Academy-Bilim Akademisi Young Investigator Award BAGEP