Application of Multi-way EEG Decomposition for Cognitive Workload Monitoring

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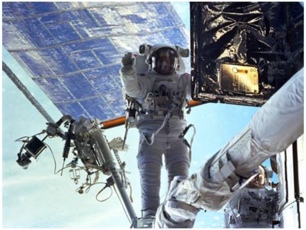
Overview

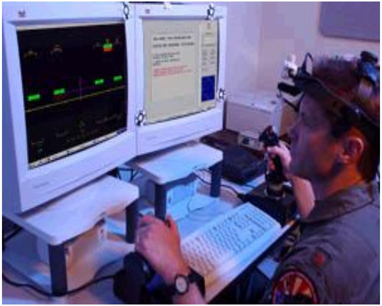
Why cognitive workload monitoring?

- Critical safety, high workload demanding, etc. environments

Experiments

- Uninhabited Air Vehicle (UAV) control



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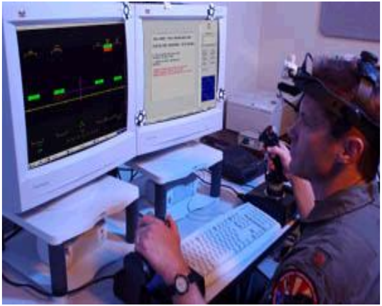

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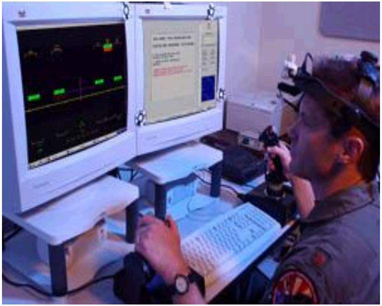

- Trained subjects were monitoring several UAVs as they flew a preplanned mission; processing SAR images (synthetic aperture radar), vehicle health control, etc.
- Different task conditions were used to control mental workload levels

Data recording

- EEG recording:

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- Normal EEG example:

Data pre-processing

- Data were segmented into 2 sec long epochs

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- Spectral representation: Thompson multitaper estimate of the power spectrum density; that is the distribution of power per unit frequency

$$P_{xx}(f) = F_x(f)F_x^*(f)$$

where $F_x(f)$ is the Fourier transform of the signal x and $*$ indicates the complex conjugate

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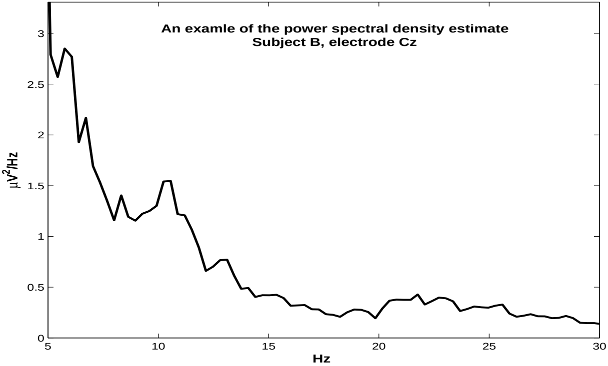
where F_x
indicates
- Example:



Data pre-processing

- Coherence representation: Cross power spectra density $P_{xy}(f)$,

$$P_{xy}(f) = F_x(f)F_y^*(f)$$

or magnituted squared (coherence)

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$$

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- Data matrix construction: $\mathbf{X}_{(I \times J \times K)}$
  I - time segments
  J - electrodes or electrode pairs
  K - PSD or CSD (coherences)

PARAFAC model

- The PARAFAC model with F factors: decomposition of the data matrix $\mathbf{X}$ using three loading matrices, $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{C}$ with elements a_{if}, b_{jf}, and c_{kf}

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- Software: proprietary m-codes developed by PDT, LLC, and subroutines from the N-way toolbox for Matlab (Andersson and Bro, 2000)

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- Set I: 2 subjects, 5 EEG electrodes (Fz, F7, Pz, T5, O2)
  Two levels of mental workload (low & high)

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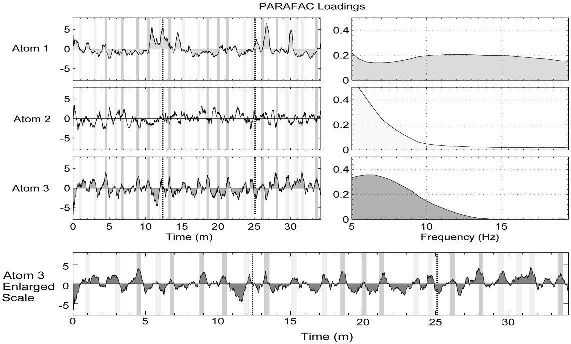
- Subject 2:



Data set II

- Set II: 6 subjects, 19 EEG electrodes (10-20 recording system)
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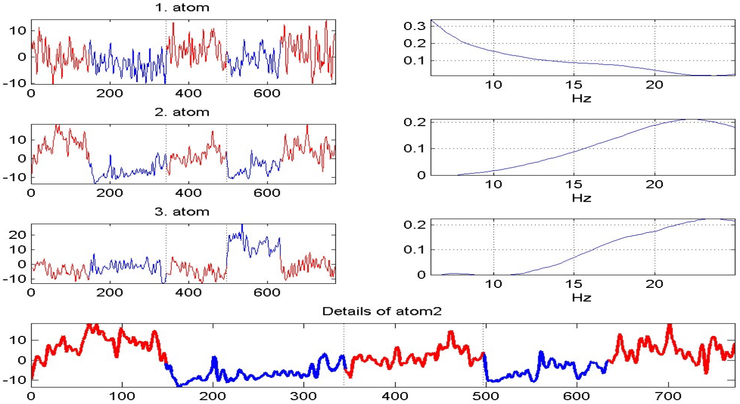
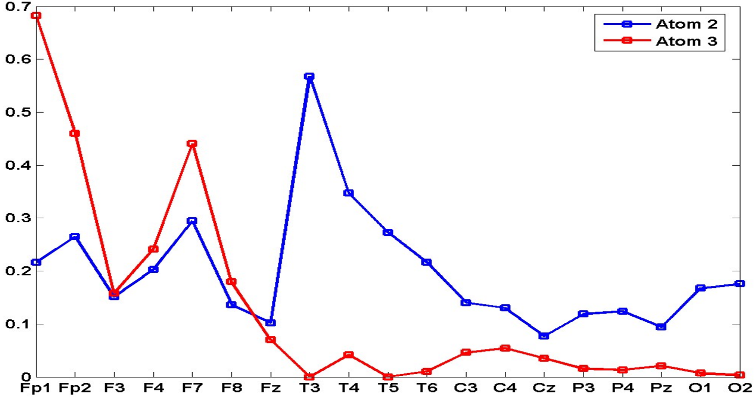
- Subject B - 19 electrodes



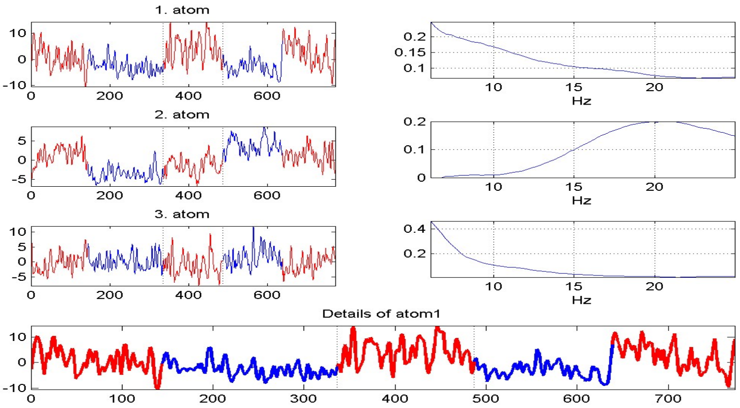
Data set II

- Spatial pattern, Subject B - 19 electrodes



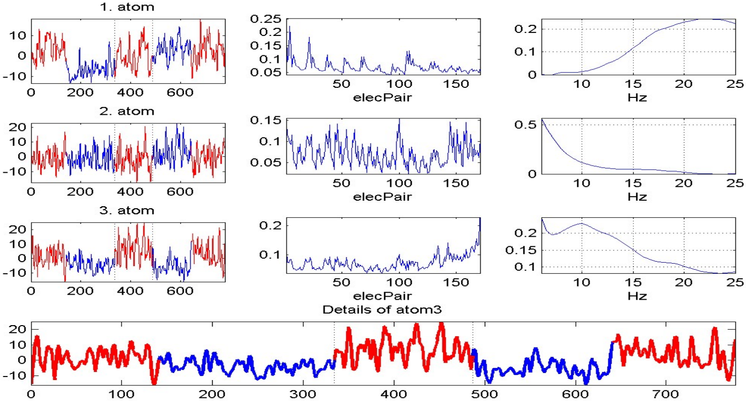
Data set II

- Subject B - reduced set of 12 electrodes



Data set II

- Subject B - coherence representation



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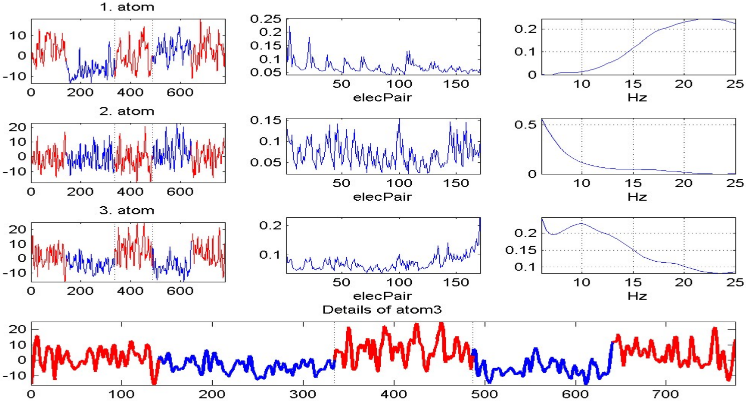
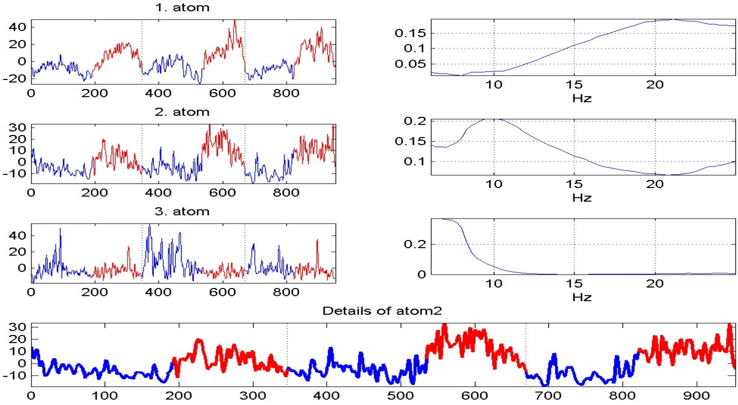


- We found high loadings in the parieto-ocipital electrode pairs

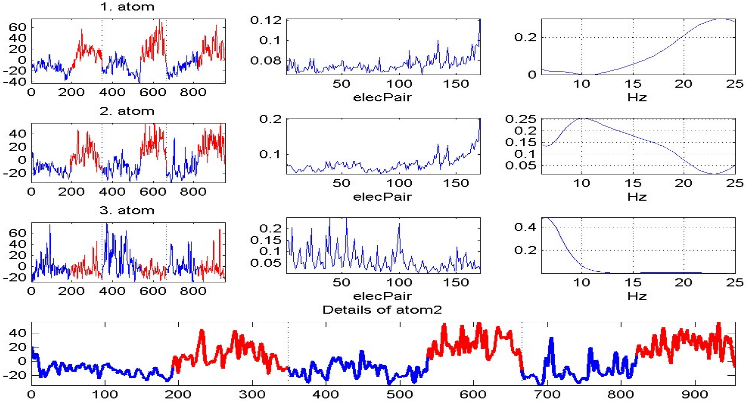
Data set II

- Subjects E,G,I, K (plotted subject E)



Data set II

- Subjects E - coherence



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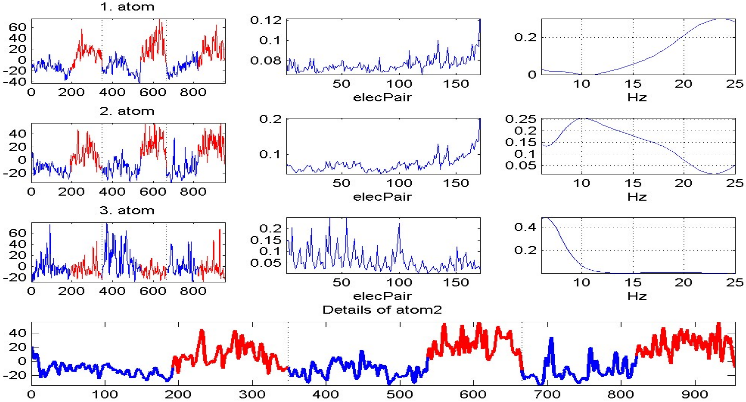
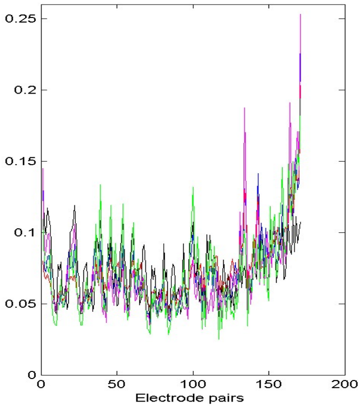
- Subjects E - coherence

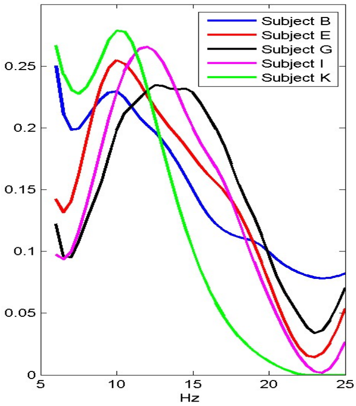


- We found the similar decomposition for subjects B, G, I, K

Data set II

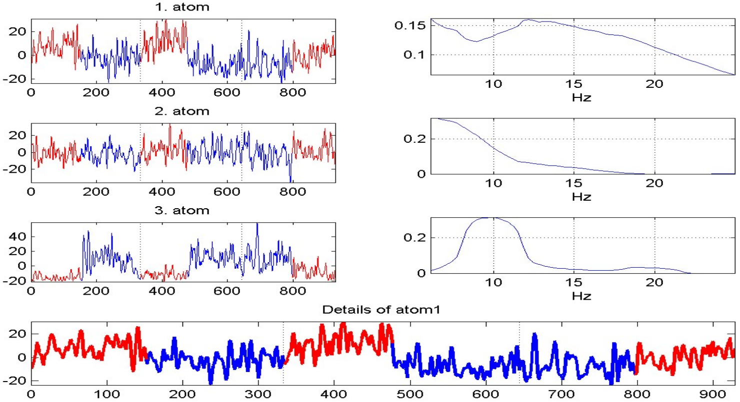
- Subjects B,E,G,I, K - coherence





Data set II

- Subjects C



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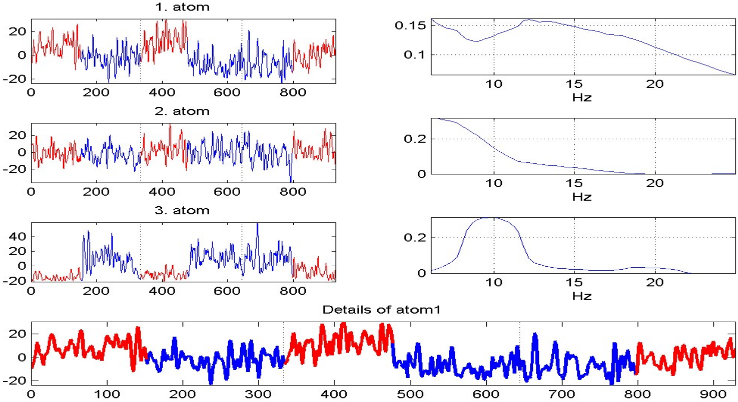
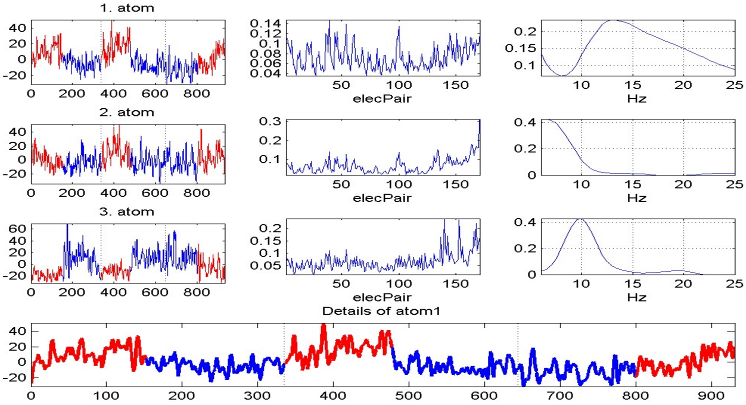


- Atom 1 - fronto-central, Atom 3 - centro-parietal

Data set II

- Subjects C - coherence



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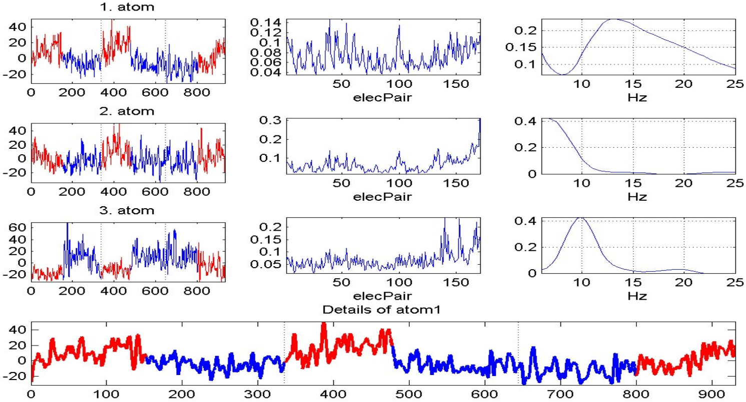

- Atom 1 - fronto-central located electrode pairs
  Atom 3 - centro-parietal & parieto-ocipital

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- The short-and long range coherence related atoms are more stable across the subjects, provide higher discrimination of the low and high workload levels and seem to be less susceptible to the movement related artifacts
- We observed similarly promising and remarkable results on additional two data sets monitoring cognitive workload and cognitive fatigue