SUPERVISED PARTIAL VOLUME EFFECT UNMIXING FOR BRAIN TUMOR CHARACTERIZATION USING MULTI-VOXEL MR SPECTROSCOPIC IMAGING

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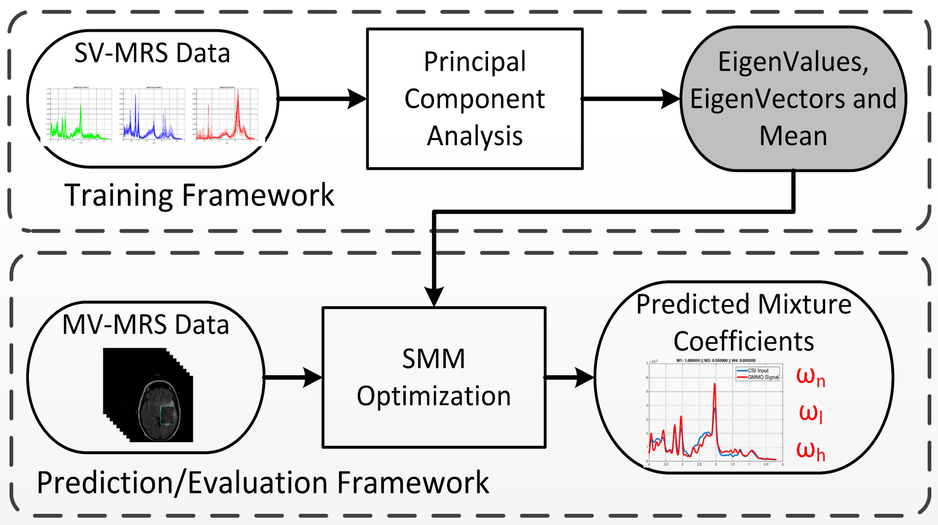
Background

o [1]H Magnetic Resonance Spectroscopy (MRS) provides detailed tissue metabolism information that has clinical potential to improve the non-invasive characterization of brain tumors.

o A major challenge faced by multi-voxel Magnetic Resonance Spectroscopy (MV-MRS) imaging is the partial volume effect (PVE), which results in a mixture of signals from two or more tissues within a MRS voxel.

o At present the definitive diagnosis of a brain tumor can only be confirmed by histological examination of tumor tissue samples obtained either by means of brain biopsy or open surgery.

Methodology



o The brain tumor grade is correlated with the MRS signal, e.g. a decrease in levels of N-acetylaspartate (NAA) indicates neuronal loss or damage [1].

o We use this relation to propose a Signal Mixture Model (SMM) for characterizing brain tissue as **n**ormal, **l**ow grade (infiltrative), and **h**igh grade (necrotic), respectively.

o PCA is applied on a database of single-voxel MRS (SV-MRS) signals to model each tissue type in terms of its mean, and variation about the mean.

Signal Mixture Model

o For each tumor grade $i \in \{n, l, h\}$, we produce a signal model

$$m_i(t) = \mu_i(t) + \sum_{k=1}^{K_i} \alpha_{ik} e_{ik}(t),$$

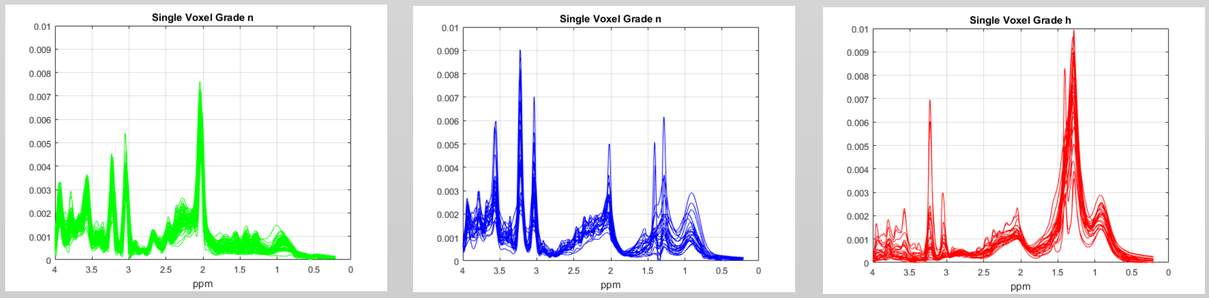
μ_i : mean
e_{ik} : eigenvectors
α_{ik} : weights allowing variation from μ_i
K_i : total number of selected eigenvectors

o A MV-MRS $x(t)$ signal can then be modelled as

$$s(t) = \omega_n m_n(t) + \omega_l m_l(t) + \omega_h m_h(t),$$

o where $\omega_n, \omega_l, \omega_h$ are mixture coefficients that represent the probability of each tumor grade in $x(t)$ and are constrained by

$$\omega_n + \omega_l + \omega_h = 1 \quad and \quad \omega_n \geq 0, \quad \omega_l \geq 0, \quad \omega_h \geq 0.$$



Visualization of variations captured in SV-MRS dataset. Shows SV-MRS signals corresponding to normal (green), low grade (blue) and high grade (red) tissues.

Signal Mixture Model Optimization

o Given a new MV-MRS signal $x(t)$, we formulate the SMM fitting as an optimization problem to determine $\omega_n, \omega_l, \omega_h$, as well as the weights α_{ik} in the model $\forall i$ and $\forall k$.

o The energy to be minimized can be expressed as

$$E = \int [x(t) - s(t)]^2 \, dt.$$

o To optimize this energy, we use gradient descent with partial derivatives

$$\frac{\partial E}{\partial \omega_i} = -2 \int [\cdot] \, m_i(t) dt, \qquad \frac{\partial E}{\partial \alpha_{ik}} = -2 \int [\cdot] \, \omega_i e_{ik} dt,$$

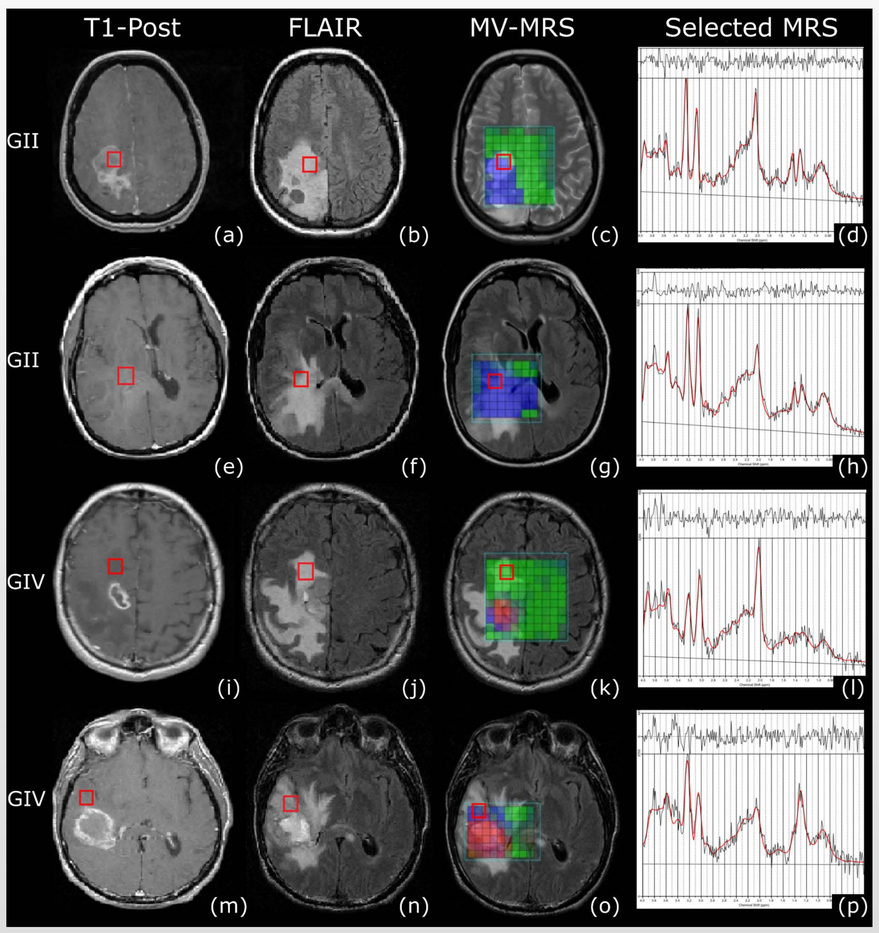
$$\text{where} \quad [\cdot] = x(t) - \sum_i \omega_i \left(\mu_i(t) + \sum_k^{K_i} \alpha_{ik} e_{ik}(t) \right).$$

o We can therefore express the gradient of the energy

$$\nabla E = \left[\frac{\partial E}{\partial \omega_n}, \frac{\partial E}{\partial \omega_l}, \frac{\partial E}{\partial \omega_h}, \frac{\partial E}{\partial \alpha_{nk}}, \frac{\partial E}{\partial \alpha_{lk}}, \frac{\partial E}{\partial \alpha_{hk}} \right].$$

Results

o Our dataset consists of 137 SV-MRS for training the SMM model and 30 MV-MRS patients, with ground truth histological diagnosis, for validation.



Visualization using heatmaps showing normal (green), low grade (blue) and high grade (red) tissues.

o We compare our SMM against histological diagnosis and convex non-negative matrix factorization (C-NNMF) method from [2]

		Grade l	Grade h		Accuracy
GIII included	Method	GII	GIII+GIV	GIV	
Yes	*C-NNMF*	66.67%	83.33%	100.0%	82.93%
	SMM	**91.67%**	**88.89%**	**100.0%**	**92.68%**
No	*C-NNMF*	58.33%	83.33%	100.0%	80.49%
	SMM	**91.67%**	**83.33%**	**100.0%**	**90.24%**
	Total Cases	12	7+11	11	

Conclusion

o The proposed SMM based method enabled non-invasive detection of brain tumor which has the potential for a computer-aided diagnosis tool with the far-reaching impact of surgical treatment and radiotherapy planning.

[1] F. A. Howe and K. S. Opstad, "1H MR spectroscopy of brain tumours and masses," NMR Biomed., vol. 16, no. 3, pp. 123–131, May 2003.
[2] S. Ortega-Martorell, P. J. G. Lisboa, A. Vellido, R. V Simões, et. al, "Convex non-negative matrix factorization for brain tumor delimitation from MRSI data.," *PLoS One*, vol. 7, no. 10, p. e47824, Jan. 2012.