

On the problem of Eigenvector sign ambiguity: *ad-hoc* solution for eigenvector decomposition-based signal and image analysis.

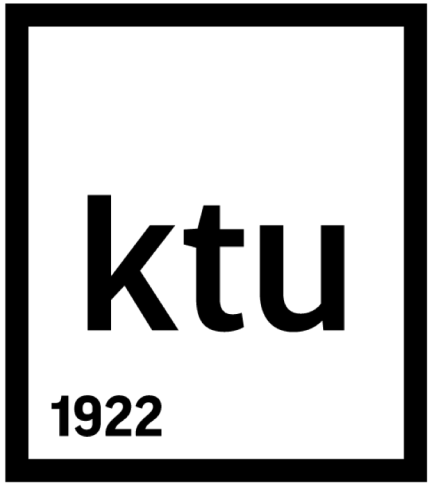
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Background: Although eigenvalue decomposition based multivariate analysis methods as Principal Component Analysis or Singular Value Decomposition are well-established and can be performed using state-of-the-art algorithms, users still face the methods' inherent problem - eigenvector polarity ambiguity. It can significantly impact the conclusions and interpretations drawn from the methods' results. Yet, no standardized mathematical method exists to resolve this problem, with only a few *ad-hoc* solutions published thus far.

Principle of PCA:

Initial data:

e.g. one picture, one ECG cardiocycle...

$$\mathbf{x}_j = \begin{bmatrix} x_{1,j} \\ x_{2,j} \\ \vdots \\ x_{m,j} \end{bmatrix}$$

Covariation matrix of initial data set:

$$\mathbf{R}_X = \mathbf{E}[\mathbf{X} \cdot \mathbf{X}^T]$$

Eigenvectors of

Covariation matrix R:

$$\text{eig}(\mathbf{R}) \Rightarrow \Phi = [\varphi_1, \varphi_2, \dots, \varphi_n]$$

Ordinary Eigenvector:

$$\varphi_i = [w_1, w_2, \dots, w_n]$$

Representation of initial data in eigenvector space:

$$\mathbf{x}_i = \sum_{j=1}^n w_{i,j} \varphi_j$$

Initial data set:

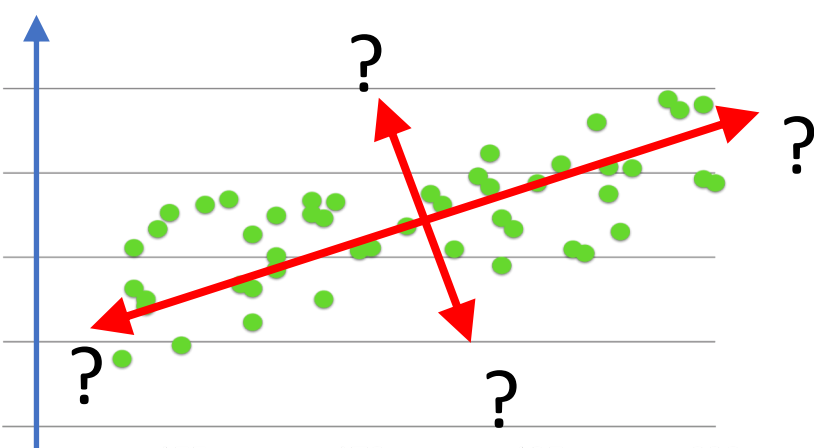
e.g. set of pictures, set of ECG cardiocycles...

$$\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n] = \begin{bmatrix} x_{1,1} & x_{1,2} & \dots & x_{1,n} \\ x_{2,1} & x_{2,2} & \dots & x_{2,n} \\ \dots & \dots & \dots & \dots \\ x_{m,1} & x_{m,2} & \dots & x_{m,n} \end{bmatrix}$$

Solution: while samples of majority of analyzed data have prominently skewed distribution, alignment of polarity of the first eigenvector coefficients with the polarity of the skewness of the corresponding original data will give the sought result. We propose a modified calculation of ordinary eigenvector:

$$\varphi_i = [\text{sign}(\text{skew}(x_1)) \cdot |w_1|, \text{sign}(\text{skew}(x_2)) \cdot |w_2|, \dots, \text{sign}(\text{skew}(x_n)) \cdot |w_n|]$$

Standard algorithms for calculation of eigenvectors are iterative and calculations can converge to eigenvector of either polarity along the same direction.

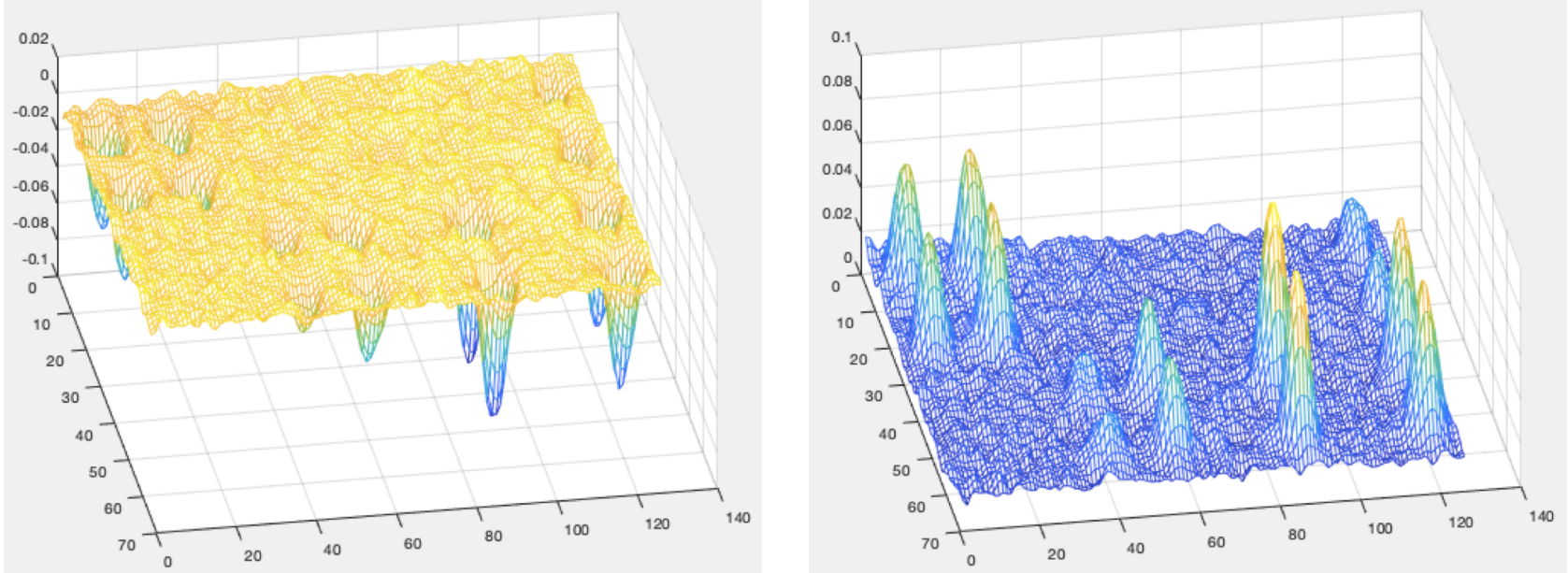
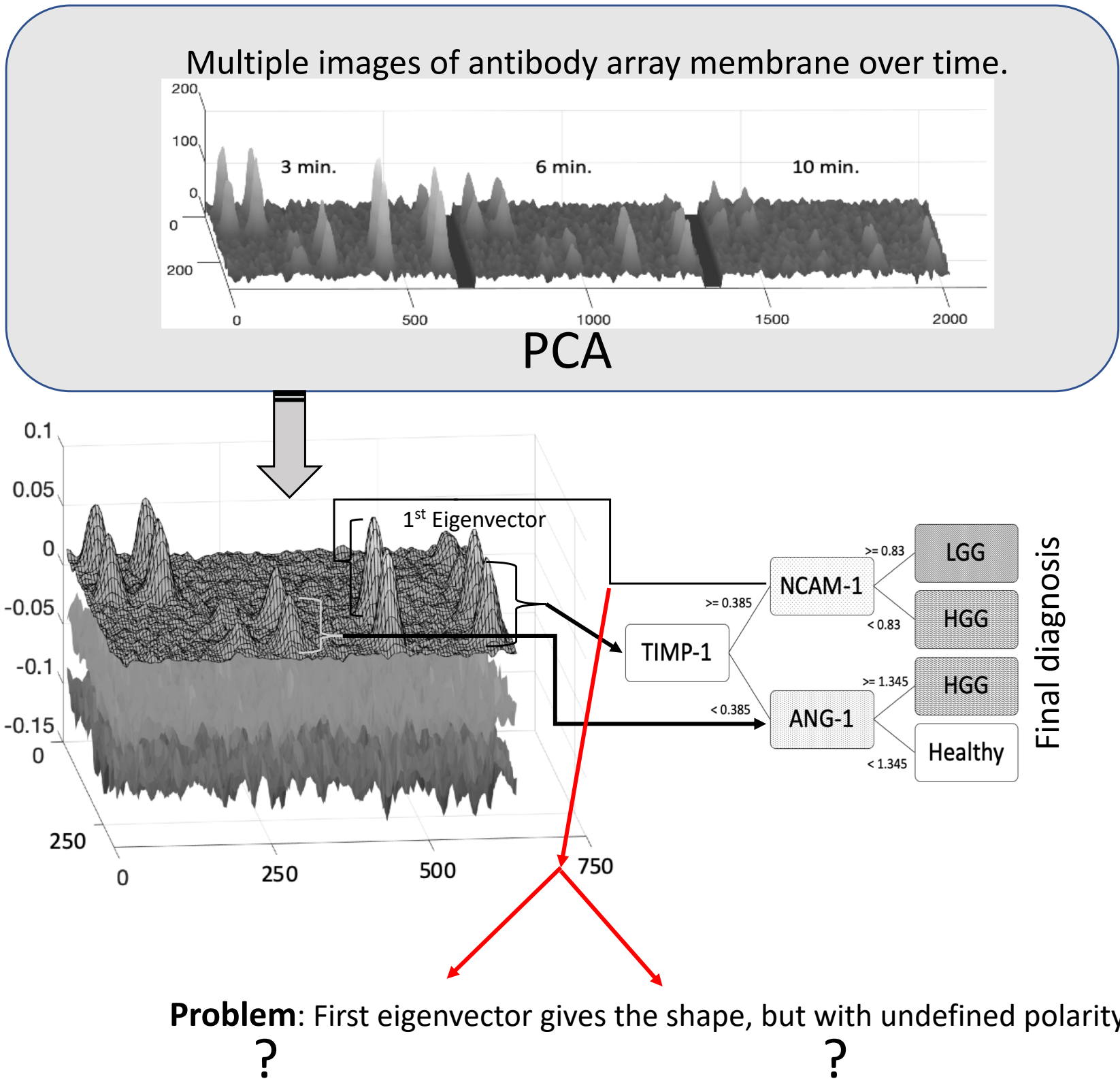
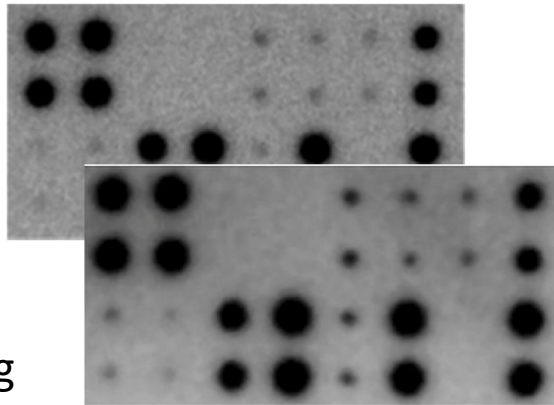


The problem: ambiguity of eigenvector polarity has no impact on final representation of initial data in eigenvector space. However, it is critical in eigenvector expansion based decomposition of complex signals or images, where the polarity of eigenvector is a part of diagnostic information.

Examples where proposed solution was used:

Weak chemiluminescence signal evaluation

Antibody array imaging for simultaneous determination of several protein concentrations. Application of Principal Component Analysis for series of repeated antibody array chemiluminescence images to extract the component representing relative values of protein concentrations, free from zero-mean noise and uneven background illumination – main factors corrupting evaluation result.



More details in: Comput Methods Programs Biomed. 2021 Nov;211:106416. doi: 10.1016/j.cmpb.2021.106416. Epub 2021 Sep 15.

Contents lists available at ScienceDirect

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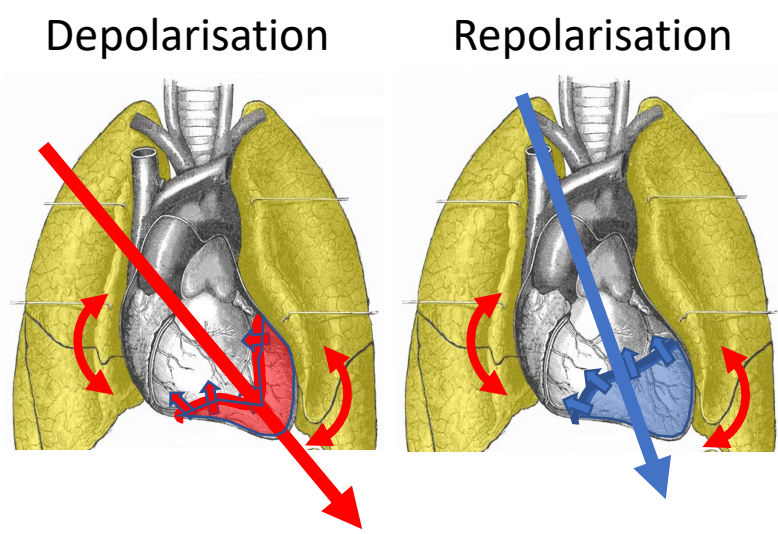
journal homepage: www.elsevier.com/locate/cmpb

Advanced image analysis-based evaluation of protein antibody microarray chemiluminescence signal improves glioma type identification by blood serum proteins concentrations

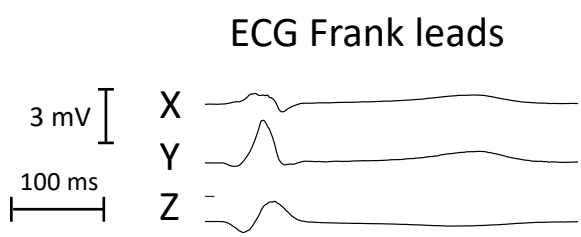
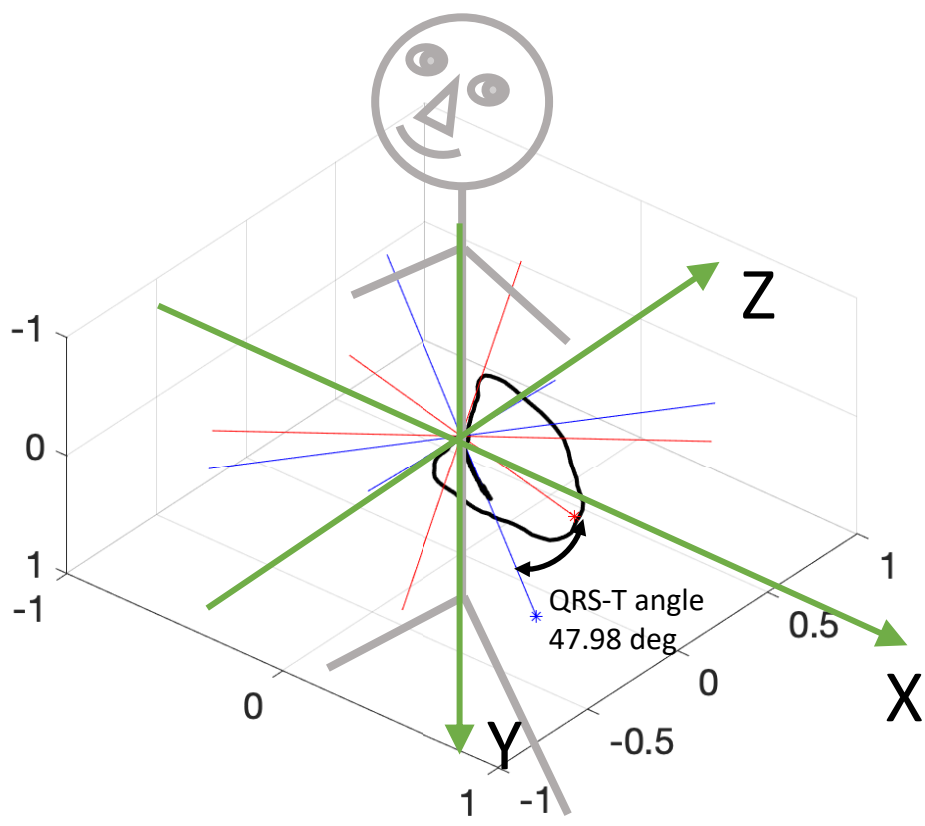
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Evaluation of changes in myocardial de-/re-polarisation front direction

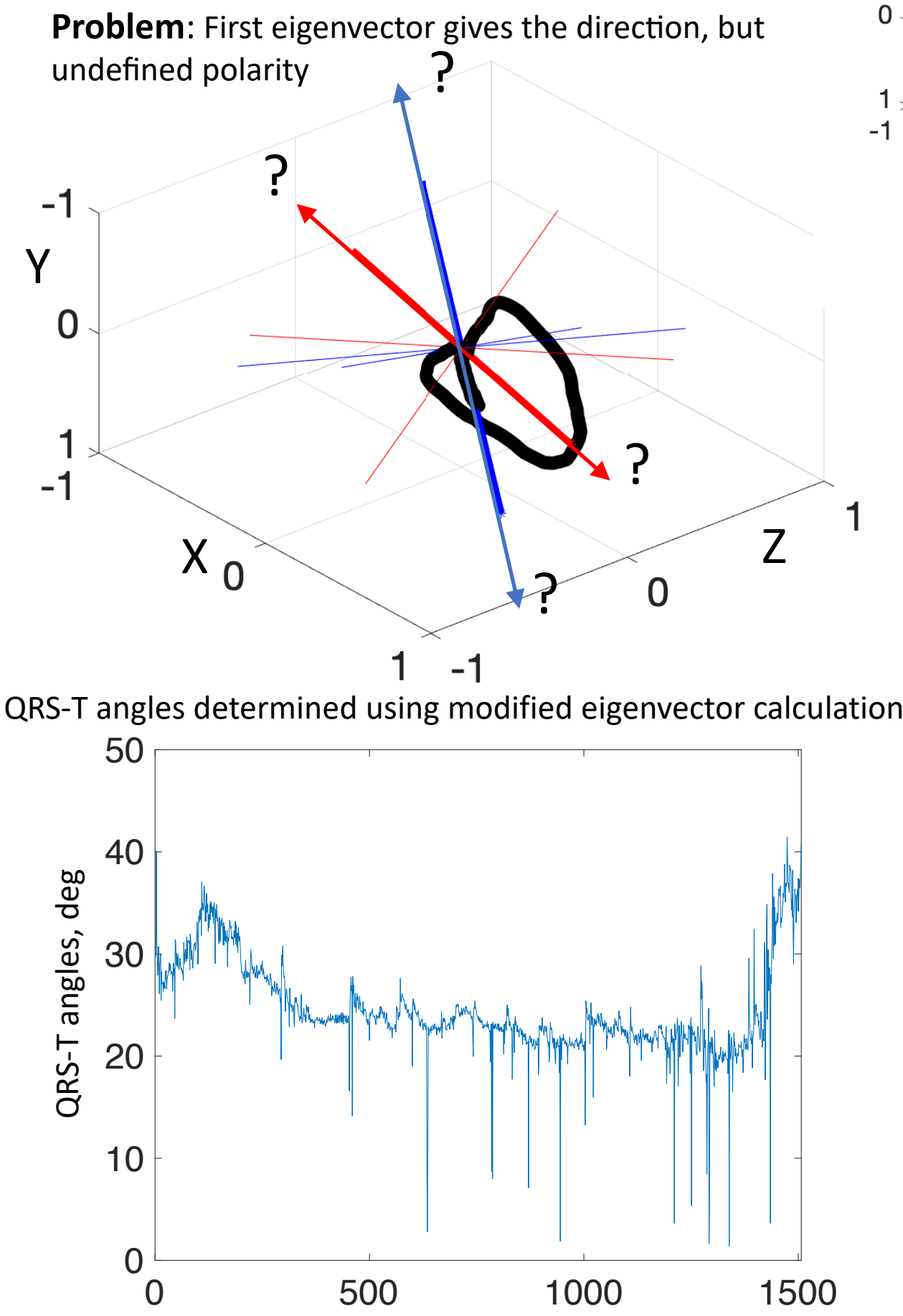
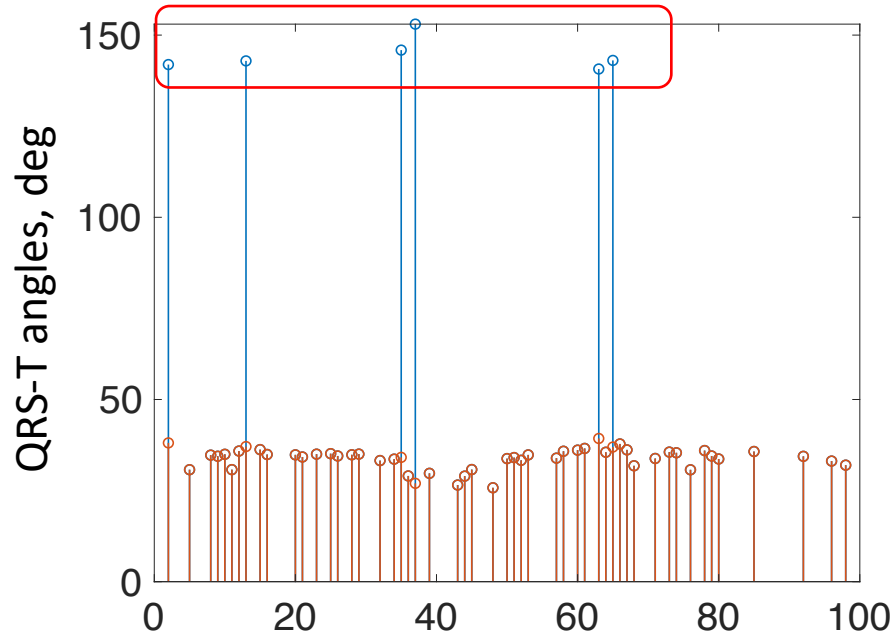
Patient conditions with impaired kidney function, including chronic kidney disease, are associated with the development of metabolic acidosis, which increases in severity with progressive loss of renal function. Metabolic acidosis and electrolyte fluctuations are causing changes in ventricular depolarisation and repolarization, what is reflected in changes of spatial de-/re-polarisation front directions. Those changes could be tracked determining main directions of spatial QRS and T loops in vectorcardiography. The directions are represented by directions of first eigenvectors of covariation matrix of samples of respected ECG components in orthogonal leads. However, standard iterative algorithms converge to determined directions of eigenvectors, but not to the polarity, what causes crucial problems in automatic follow up of the patients.



The principle of vectorcardiographic determination of angle between main directions of depolarisation and repolarisation of ventricles (so called QRS-T angle).



Problem: errors due to eigenvector polarity ambiguity



This work was supported by the project "KidneyLife" funded by the EU Structural Funds under the grant No. 01.2.2-LMT-K-718-01-0030.



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