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Reconstruction of Signal in Plastic Scintillator of PET Using Tikhonov Regularization

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Abstract : The J-PET scanner, which allows for single bed imaging of the whole human body, is currently under development at the Jagiellonian University. The J-PET detector improves the TOF resolution due to the use of fast plastic scintillators. Since registration of the waveform of signals with duration times of few nanoseconds is not feasible, a novel front-end electronics allowing for sampling in a voltage domain at four thresholds was developed. To take fully advantage of these fast signals a novel scheme of recovery of the waveform of the signal, based on ideas from the Tikhonov regularization (TR) and Compressive Sensing methods, is presented. The prior distribution of sparse representation is evaluated based on the linear transformation of the training set of waveform of the signals by using the Principal Component Analysis (PCA) decomposition. Beside the advantage of including the additional information from training signals, a further benefit of the TR approach is that the problem of signal recovery has an optimal solution which can be determined explicitly. Moreover, from the Bayes theory the properties of regularized solution, especially its covariance matrix, may be easily derived. This step is crucial to introduce and prove the formula for calculations of the signal recovery error. It has been proven that an average recovery error is approximately inversely proportional to the number of samples at voltage levels. The method is tested using signals registered by means of the single detection module of the J-PET detector built out from the 30 cm long BC-420 plastic scintillator strip. It is demonstrated that the experimental and theoretical functions describing the recovery errors in the J-PET scenario are largely consistent. The specificity and limitations of the signal recovery method in this application are discussed. It is shown that the PCA basis offers high level of information compression and an accurate recovery with just eight samples, from four voltage levels, for each signal waveform. Moreover, it is demonstrated that using the recovered waveform of the signals, instead of samples at four voltage levels alone, improves the spatial resolution of the hit position reconstruction. The experiment shows that spatial resolution evaluated based on information from four voltage levels, without a recovery of the waveform of the signal, is equal to 1.05 cm. After the application of an information from four voltage levels to the recovery of the signal waveform, the spatial resolution is improved to 0.94 cm. Moreover, the obtained result is only slightly worse than the one evaluated using the original raw-signal. The spatial resolution calculated under these conditions is equal to 0.93 cm. It is very important information since, limiting the number of threshold levels in the electronic devices to four, leads to significant reduction of the overall cost of the scanner. The developed recovery scheme is general and may be incorporated in any other investigation where a prior knowledge about the signals of interest may be utilized.

Keywords : plastic scintillators, positron emission tomography, statistical analysis, tikhonov regularization
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