Feasibility of Image Reconstruction from Triple Modality Data of Yttrium-90

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***Abstract*—The recent implementation of the first clinical triple modality scanner in STIR enables investigation of the possibility of triple modality image reconstruction. Such a tool represents an important step toward the improvement of dosimetry for theranostics, where the exploitation of multi-modality imaging can have an impact on treatment planning and follow-up. To give a demonstration of triple modality image reconstruction we used data from a NEMA phantom that was filled with Yttrium-90 (^{90}Y), which emits Bremsstrahlung photons detectable with SPECT as well as gamma rays that can go through pair production, therefore creating positrons that make PET acquisition possible. The data were acquired with the Mediso AnyScan SPECT/PET/CT. Different ways of including multiple side information using the kernelised expectation maximisation (KEM) and the Hybrid KEM (HKEM) were used and investigated in terms of ROI activity and noise suppression. This work presents an example of application with ^{90}Y but it can be extended to any other radionuclide combination used in Theranostic applications.**

I. Introduction

The exploitation of multi-modality, like computed tomography (CT), single photon emission CT (SPECT), and positron emission tomography (PET), can have an impact on the accuracy of treatment planning and post-treatment imaging assessment and dosimetry. There are different radionuclide combination being used for different types of cancer, however one in particular, Yttrium-90 (^{90}Y), allows the acquisition from both PET and SPECT. This is because of its capability of emitting Bremsstrahlung, detectable with SPECT, as well as gamma rays with high enough energy to go through pair production, therefore creating positrons and making PET acquisition possible.

To give a demonstration of triple modality image reconstruction we used data from a NEMA phantom that was filled with ^{90}Y and scanned with SPECT-CT first and PET consecutively using the tools implemented in STIR [1,2]. Recently, it has been shown that PET images can be used to improve SPECT quantification [3] using the HKEM algorithm [4]. In this work we aim to use KEM, HKEM and multiplexing HKEM (MHKEM) [5] to exploit PET, SPECT and CT information to reconstruct PET and/or SPECT. The difference between the aforementioned algorithms is that KEM only uses the anatomical side information, the HKEM allows the use of iterative functional images as extra side information and MHKEM allows the use of multiple images (iterative or not) as side information. Because the probability of positron emission for ^{90}Y is very low, a clinical PET acquisition is extremely noisy. As a consequence, image quality and quantification are affected. For this reason we first focus on the improvement of PET image reconstruction when using PET, SPECT and CT side information.

Different HKEM reconstructions were performed using all the side information alone or combined and were compared with MHKEM.

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II. Methods

A. Phantom Data

Data were acquired at the National Physical Laboratory (NPL), UK, using the Mediso AnyScan SCP. The NEMA phantom contained 6 spherical inserts of different volume and the same activity concentration. The diameter of each sphere was 10 mm, 13 mm, 17 mm, 22 mm, 28 mm and 37mm and the background was filled with water. The data were acquired for 2 hours with SPECT and 4 hours with PET.

B. Reconstruction Setup

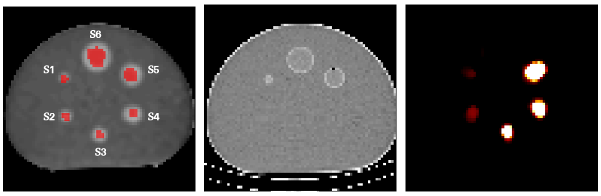
Support for the Mediso AnyScan SCP has previously been implemented in the Software for Tomographic Image Reconstruction (STIR) [6]. The data were reconstructed using OSEM with Gaussian post-filter and no PSF (OSEM-noPSF), OSEM with PSF and Gaussian post-filter (OSEM), HKEM and KEM with only CT (HKEMct, KEMct, HKEM and KEM with only SPECT (HKEMspect, KEMspect), and MHKEM and MKEM which use both SPECT and CT images as side information. The images used as side information were manipulated to introduce spatial inconsistencies between PET, CT and SPECT by removing spheres, and they are reported in Figures 1(b) and 1(c).

Because of its low resolution the ^{90}Y SPECT image was reconstructed using HKEM with CT side information. As a consequence HKEMspect and KEMspect can be regarded as triple modality methods. As a consequence, there are effectively four ways of using triple modality information in this work:

1) The SPECT is reconstructed using HKEMct and HKEMspect is used to reconstruct PET;
2) similarly using KEMspect to reconstruct the PET data;
3) the PET image is reconstructed using MHKEM with SPECT and CT as side information;
4) the PET image is reconstructed with MKEM.

These options were compared with all the different combinations of side information using KEM and HKEM.

The image size was 161×161×75, while the voxel size was 4×4×4 mm^3. SPECT images where resampled to match the PET images. An extensive optimisation of the kernel parameters was performed in terms of ROI value and coefficient of variation (CoV), and to avoid the



(a) (b) (c)

Fig. 1. CT image with the chosen ROIs for the phantom (a), manipulated CT image (b), and manipulated SPECT image (c) for kernel side information.

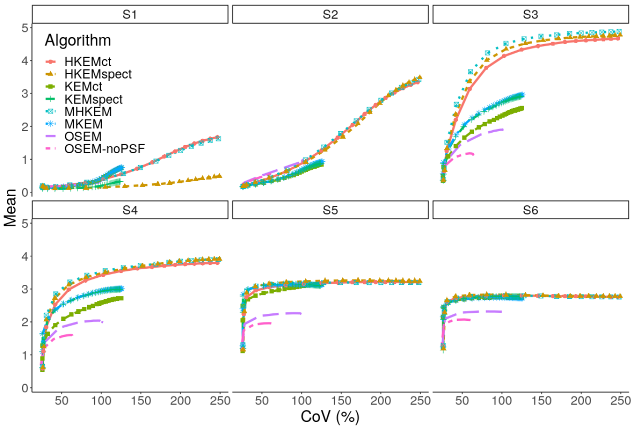


Fig. 2. Comparison of mean value for each ROI between reconstructed images of the NEMA phantom with OSEM-noPSF, OSEM, KEMspect, KEMct, MKEM, HKEMct, HKEMspect, and MHKEM.

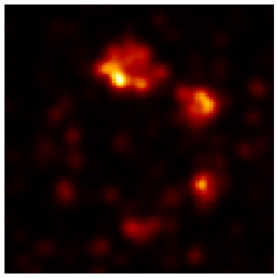


Fig. 3. Reconstructed image of the NEMA phantom with OSEM using 2 mm voxel size.

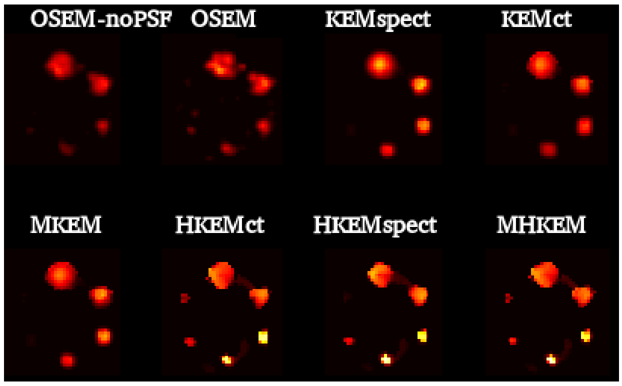


Fig. 4. Reconstructed images of the NEMA phantom with OSEM-noPSF, OSEM, KEMspect, KEMct, MKEM, HKEMct, HKEMspect, and MHKEM.

appearance of artefacts. As a result, the number of subsets was set to 9, the kernel parameters are reported in Table I.

TABLE I

MHKEM selected parameter values	
Neighbours	5×5×5
functional edge σ_p	0.5
anatomical edge spect σ_{ms}	30
anatomical edge ct σ_{mc}	0.03
spatial distance σ_{dp}/σ_{dm}	5

The analysis was carried out using segmented regions from the CT image, as reported in Figure 1(a), to calculate the mean and maximum value and the coefficient of variation (CoV).

III. Results and Discussion

Figure 2 reports the mean ROI value in each sphere, numbered from smallest to largest, and compares all the algorithms mentioned above. The highest values at fixed CoV are obtained using MHKEM, HKEMspect and HKEMct with a maximum improvement of 14% between MHKEM and HKEMct and up to 200% between MHKEM and OSEM. It can be noticed that the biggest sphere does not have the highest values. We hypothesise that this is due to the long acquisition time in which adhesion and settling effects have occurred in all the spheres. This can be seen better in Figure 3 which shows the OSEM reconstructed image with voxel size 2 mm. There is an evident accumulation of activity in the surface of the spheres S6, S5 and S4. For this reason the multi-modality reconstruction may not have provided the expected activity increase in those regions. This is especially so for HKEM where the PET image is also used and the internal part of the sphere may have been treated as a cold region. A phantom experiment with higher activity and shorter acquisition time may need to be carried out.

Figure 4 provides a qualitative comparison between the images reconstructed with OSEM-noPSF, OSEM, KEMspect, KEMct, MKEM, HKEMct, HKEMspect, and MHKEM. The improvement in image quality of the images obtained with guided algorithms compared to OSEM-noPSF images is noticeable. In particular, it can be seen that when no iterative PET information is used (KEM) the images are more blurred especially in those spheres that lack side information, such as S3 and S4 for KEMct and MKEM. In addition, S1 and S2 are not visible for KEMspect, KEMct and MKEM. The highest contrast can be seen in the images reconstructed with HKEMct, HKEMspect, and MHKEM. When looking carefully at these last three images, one can notice that S1 is very faint for HKEMspect and only when PET and CT side information are used it is possible to detect it. Except for S1, and S5 the other spheres look similar between MHKEM and HKEMspect. S2, S3 and S4 look more blurred and deformed for HKEMct than MHKEM because of the missing information in the CT image of these spheres. It has to be noted that even though we are able to detect S1 with HKEMct and MHKEM, this is only possible because of the CT information, however, in practice, the CT might not provide sufficient contrast of a cancerous lesion with patient data. Clinical data will be crucial to demonstrate the impact of triple modality reconstruction. The method could be used to take advantage of all the information acquired during a theranostic procedure, to test new radiopharmaceutical cocktails and so on.

IV. Work in Progress

We are currently exploring the feasibility of reconstructing triple modality clinical data using ^{90}Y.

V. References

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