

Multi-modality imaging on track

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Accurately registered images of complementary biomedical imaging devices, for example images representing tissue function (PET or SPECT) registered with structural/anatomical images obtained with CT or MRI, are of crucial importance for research, diagnosis and patient treatment. Several multi-modal tomography approaches have already proven to significantly enhance accuracy of diagnosis and patient management. The main reason for this is that molecular processes that show up at the site of (for example) a tumour or infection process can be accurately localised in an anatomical framework and attributed to a specific tissue or organ. Such combination of modalities presents added diagnostic information compared with either of the employed modalities used in isolation. Furthermore, there is potential to enhance reconstruction and improve quantification utilising the combined information from multiple modalities.

Until recently, pure software-based methods based on either rigid body or non-rigid algorithms were used for image registration. There are several comprehensive reviews available covering both intra-modality and inter-

modality registration [1–3]. In general, however, when applied to multi-modal studies involving emission tomography, these methods have been unable to deliver sufficiently robust registration for general clinical imaging practice. For many parts of the body the registration is complicated, for instance because changes in the patient's position cause organs and tissues to shift relative to each other, necessitating computationally slow, sometimes ill-defined, non-rigid approaches. More importantly for SPECT, some of the applications where registration has most clinical potential involve the localisation of specific uptake where there often is insufficient information outside the target tissue to permit accurate multi-modal registration. In addition, the logistics of retrieving data from multiple sites is seldom straightforward.

The recognition of this problem led to the introduction of combined molecular and structural imaging devices: PET/CT [4, 5] and SPECT/CT [6, 7]. SPECT/CT, originally suggested by Hasegawa and co-workers, predated PET/CT as an attempt to improve on the low-cost transmission scanning that was developed for cardiac attenuation correction (whose commercial implementation proved to be problematic [see 8]). Both PET/CT and SPECT/CT can be very successful in eliminating the organ shift problem. In 2000, the modern PET/CT scanner, as proposed by Townsend and Nutt, was named by *TIME Magazine* as the medical invention of the year, and indeed it has maintained a significant impact on clinical practice. Today, sales in PET involve almost exclusively PET/CT systems. This is not the case yet with SPECT/CT scanners although the installed base is rapidly growing. One reason for the slower acceptance of SPECT/CT is the relative cost of CT and SPECT, especially considering the relatively low percentage of studies where SPECT/CT imaging is indicated. As a consequence there was an initial trend to offer slow,

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low-cost CT systems with compromised performance and reliability, which has tended to further hinder development. It should be borne in mind that CT was successful in significantly reducing the acquisition time of standard attenuation-corrected PET whereas in SPECT it is normally an add-on procedure; the significant acquisition time for slow CT systems has further influenced acceptance.

Knowing exactly what is where

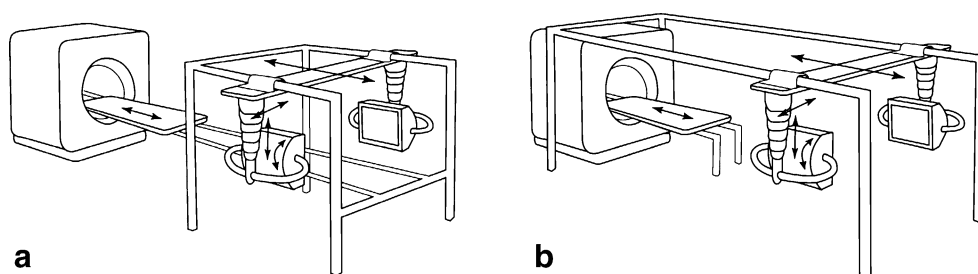
The principle used in multi-modal hardware approaches is that one takes care that both the spatial relation between the scanners and the translations made by the multi-modality bed that carries the patient from one scanner to the other are known exactly. Then, the transformations needed to overlay images are known and image registration becomes trivial. Possibilities to accomplish this include (a) the use of a bed and a track that permit transportation of the patient over a slightly longer (but stable!) trajectory than is used for a single scanner in order to position the patient in two scanners mounted back to back in close proximity (this is how most commercial SPECT/CT or PET/CT scanners are constructed), (b) the use of a bed that docks to different systems [successfully applied for imaging of small animals (e.g. 9)] and (c) the use of long tracks over which a multi-modal bed with a patient is transported through different independent stand-alone scanners ([10, 11]; Fig. 1a). An introduction and overview of dual-modality systems was recently published by Cherry [12]. It is worth noting that the existing commercial dual-modality systems operate in sequential mode so that misregistration is still possible and indeed observed in some studies; software registration (usually rigid) still plays an important role in facilitating the final alignment.

A flexible, track-based and modular approach to SPECT/CT

In the paper “Development of a cost effective modular SPECT/CT scanner” by Bailey et al. [13], an alternative to

the more costly commercial SPECT/CT systems is presented. This alternative consists of a CT system with a sliding CT bed that is placed on a track in the floor and a linked SPECT system (in this case, a Philips Skylight, which is a flexible SPECT device that is suspended from a robust framework). Ideally the supports used to translate the SPECT system are exactly aligned with the tracks used for the bed. As with the commercial SPECT/CT devices, this modular and track-based method allows acquisition of registered nuclear medicine and CT images because the patient can stay on the same bed. The specific approach validated by Bailey et al. has several advantages over integrated SPECT/CT: (a) despite the rather small footprint, both scanners can be used in parallel, (b) the footprint is adaptable to different site configurations and (c) each scanner can be replaced independently. The authors also point out that their approach is cost effective: in their case a refurbished CT module was used (raising a relevant side issue: “What CT performance is sufficient for use with SPECT?”). There is an alternative approach though: to use brand new and cutting-edge SPECT and CT “modules” each optimised to the clinical needs. This may still be cost-effective compared with present commercial SPECT/CT approaches too, because there is no need to replace the complete SPECT/CT or PET/CT when the technology of one component is outdated (indeed, the life expectancies of the two systems tend to be quite different) or when the integrated system does not meet expectations. Therefore a modular SPECT/CT and PET/CT approach may be an attractive option for departments with limited resources (for instance in developing countries) or departments that can permit themselves always to have the best available module of each kind plugged into their imaging chain. A further approach that has definite appeal is the possibility of operating a single central CT system (or MR system) in combination with multiple other SPECT (and/or PET) instruments: cross-calibration of spatial orientation should be no harder for multiple tracks than for a single track. At a time when cost containment is important, this could provide a very effective model. It is not clear yet, however, whether, and in which countries, such implementations will be hampered by patent issues: a variety of rail-based

Fig. 1 Some modular SPECT/CT solutions (art impressions derived from [10]). **a** Long bed track. **b** Short bed track and long rails for the SPECT system



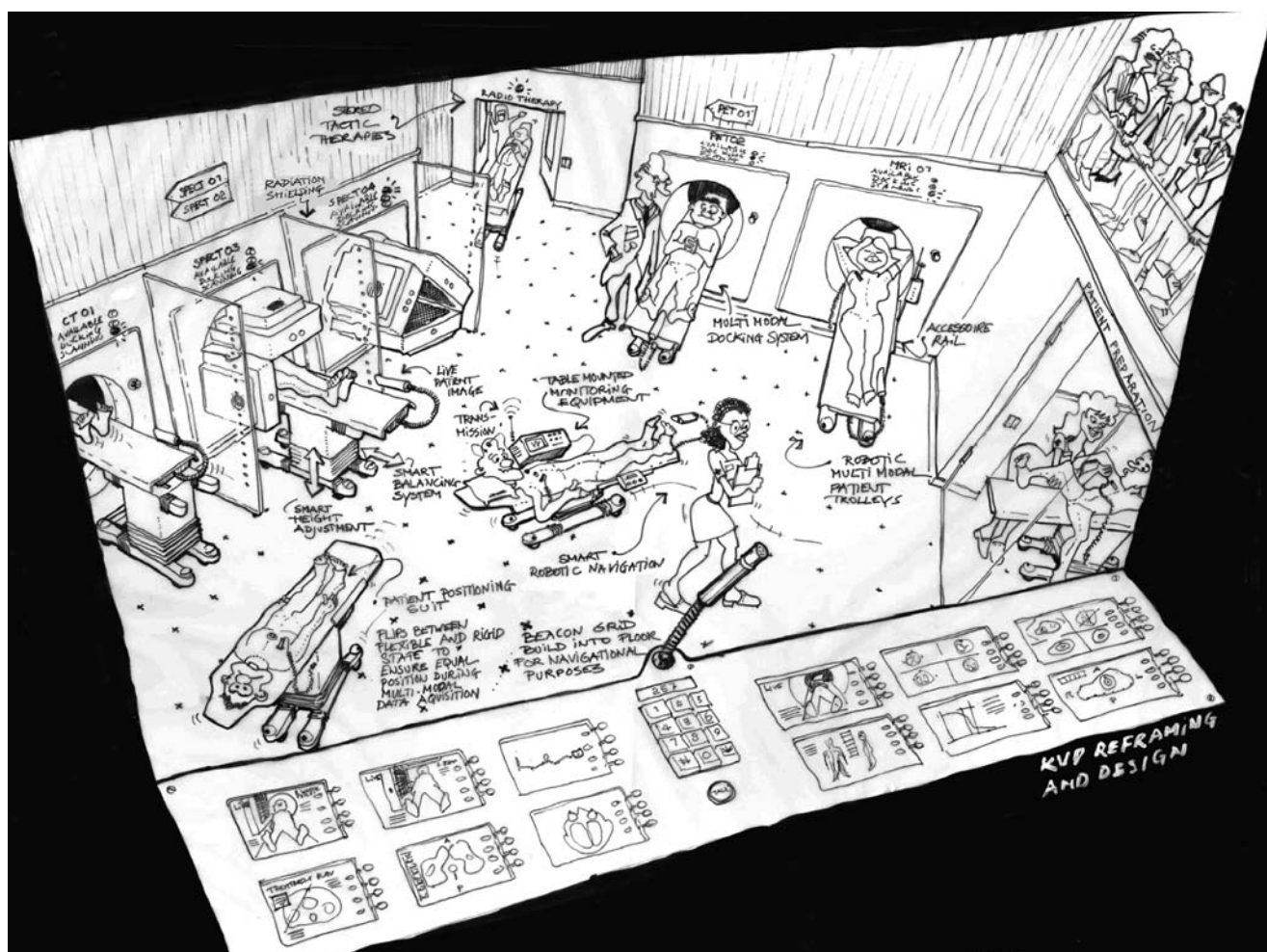


Fig. 2 Imaging Department of the Future? Artist's impression of an imaging department with "smart" (position aware) lift trucks with multi-modality beds that can be rotated and translated. The mini-beds and trucks have height adjusters, a storage area for patient liquids,

means to fixate the patient, an adjustable counter-weight and a transmitter for broadcasting patient information such as ECG, and could rely on beacons for positioning. (Illustration by Gijs Ockeloen, KVD Reframing and Design, Amsterdam)

approaches (including the one described by Bailey et al.) have been previously patented by Philips in the US ([10]; Fig. 1a,b). This also formed the basis for the commercial "open" PET/CT system, which permits access between PET and CT gantries.

What is the difference?

The SPECT/CT and PET/CT machines that have come onto the market in the past couple of years are similar to the rail- or track-based approaches proposed by Karmalawy et al. and Bailey et al., in the sense that the patient stays on a single bed that can be moved axially through the field of view of both scanners. In the commercial SPECT/CT and PET/CT scanners the integration is in fact still limited because these combined machines, based on two scanners placed in close proximity under a single cover, do still carry

out sequential scanning. Probably the most advanced integration aspect is the dedicated user interface, which allows operation of both machines from a single console.

That the distance between the scanners is somewhat bigger in the rail-with-sliding-bed approaches of Bailey et al. and Karmalawy et al. should barely add to the total time needed to acquire a combined emission and transmission scan. The total acquisition time is dominated by the emission acquisition and patient setup times. Even if larger distances were to be required, e.g. up to a few tens of metres, this would not necessarily add a large fraction of time to a total scanning procedure. However, a requirement for widespread commercialised implementation is that acquisition at independent scanners including the patient transportation can be readily defined from a single console, which involves a significant amount of engineering and standardisation when systems of different manufactures are used.

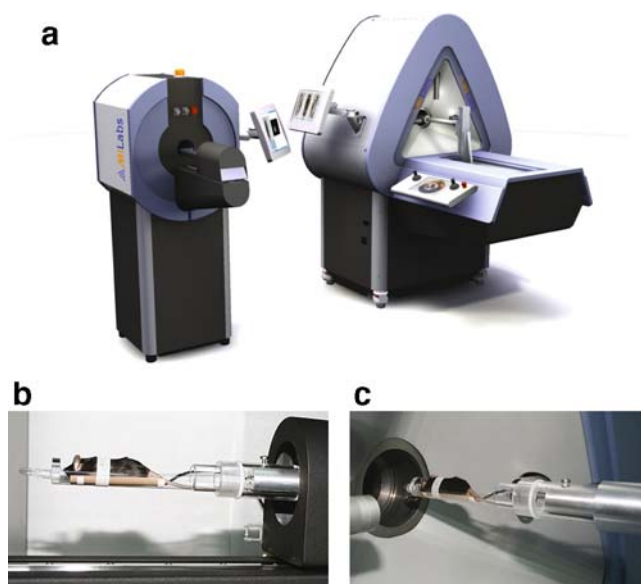


Fig. 3 Modular approach to combined small animal SPECT/CT with the animal bed clicking onto the different systems (**b**, **c**). Such an approach can be extended to a number of additional devices

Modular or integrated many-modality imaging?

The hunger for registered images will not stop with the widespread availability of SPECT/CT and PET/CT, and perhaps also not with the SPECT/MRI and PET/MRI combinations that are under development. Based on the imaging task at hand, physicians want to choose the best combination of imaging modalities, and want to analyse and treat the disease or injury with all the acquired images registered. For economic and throughput reasons they will also like an approach that allows them to use all modalities in parallel and completely independently. Therefore it is interesting to consider expanding track-based and modular multi-modality approaches to a broader variety of modalities (e.g. PET, SPECT, CT and MRI, to mention just a few popular ones). When you think about it, there are several reasons to avoid the development of machines with more than two modalities. But are track-based approaches really an alternative? When MRI is included in the chain, larger distances are required than with other modalities, and railways have their own pros and cons, as one knows from experience, travelling with national rail services. Instead of rails, (fork-)lift trucks with a multi-modality patient bed that nicely docks into each different modality may be more suitable (Fig. 2). The development of such “patient transfer” devices may involve significant engineering steps but could be very useful in combination with stereotactic therapies including surgery and radiotherapy. In many respects, however, the limitation in registration is not the bed, but the patient: maintaining patient position throughout the transfer between devices, whether via tracks or truck,

continues to be a limiting factor even with custom-made patient restraints. Cross-calibrated optical tracking systems, similar to those used in patient motion tracking [e.g. 14], could verify patient (rather than bed) orientation between independent systems.

Animal many-modality imaging

With animal imaging, the variety of imaging procedures is even larger than in clinical imaging, since almost every research question to be answered requires a unique protocol. Also, the progress being made in the quality of small animal imaging devices is rapid. For example, prior to the end of the 1990s, no dedicated commercial SPECT devices were available. In 2000 the resolution was typically a few millimetres, while presently sub-half millimetre resolution systems are on the market [15]. The fast progress in performance may stimulate fast replacement of individual imaging modules (Fig. 3).

Of course, the logistics of transferring animals between modalities has one important advantage compared with the human situation: the use of anaesthetics virtually guarantees stable subject position throughout the procedure.

Conclusion

Various rail-based, docking and click-over approaches have been proposed for combining anatomical and nuclear medicine images, for humans as well as for small animals. If modular aspects can be well utilised, this will help to reduce costs and will facilitate the replacement of redundant modules. Realising such approaches on a large scale and for all important tomographic imaging modalities is a challenging task, involving new industrial standardisations, inter-departmental politics and the development of multi-modal acquisition platforms that preferably will be compatible with systems of different manufacturers. Track- and docking-based systems, including those using compact computer-steered (fork-)lift trucks are interesting not only for SPECT/CT but also for several other present and future multi-modality approaches. Radical changes in room layout to accommodate patient transfer between multiple systems may be commonplace in the imaging departments of the future.

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