Hybrid x-ray/MR system and other hybrid imaging modalities

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ABSTRACT

The past few decades have seen phenomenal growth in medical imaging technologies and their impact in biomedicine. This trend will continue, and indeed expand with the development of new techniques. However, another development likely to have major importance is the development of systems offering combined modality imaging in the same platform. Such hybrids include PET/CT, PET/MRI, SPECT/CT, and x-ray/MR systems, and offer not only the convenience of access to multiple modalities in the same session, but more importantly, synergistic uses in which the combined modality is more than the simple sum of previous methods. An simple example is the use of CT data for attenuation correction in PET and SPECT imaging, which is greatly facilitated in a hybrid system.

In our own work, we have developed a hybrid x-ray/MR system for image-guided interventions. It brings together the high spatial and temporal resolution of x-ray fluoroscopy with the 3D imaging capabilities, soft tissue contrast, and sensitivity to physiological processes of MRI. System development required exploration of a number of interesting problems, including the effect of high magnetic fields on x-ray tubes. The system has been used for several diagnostic and minimally invasive applications, including biopsies, arthrograms, and TIPS procedures.

INTRODUCTION

Decades of research and development have produces a number of very powerful imaging modalities. This trend will certainly continue, and if past history is any guide, the pace of advance is likely to continue to accelerate. If so, we will see improvement in each of the imaging methods, the development of new imaging techniques and new clinical applications.

It is interesting to note that when recent ones came on the scene, the demise of some older ones was predicted. The development of CT brought on predictions of the end of nuclear medicine, and the introduction of MRI caused some to predict that CT would be replaced. This has not happened, and with few exceptions all the modalities are still being used and bring significant benefit. The explanation is that each yields different information; each has its strengths and weaknesses, and each brings the best balance of capabilities for some applications. Some modalities yield anatomical or morphological information while others produce physiological information. Some have high spatial resolution and provide 3D information while others have rapid imaging capability and support highly interactive manipulations. Some are noninvasive while others are portable.

Nonetheless, while, for any application a particular modality may possess a better blend of relevant strengths compared to its weaknesses, one should recognize that each has weaknesses. As a result, selection of a particular modality for a given application may well constitute a compromise between the advantages of one modality versus those of another. In general, no modality is perfect. One may be in a position where perhaps one modality is preferred for one part of the procedure while another is preferred at a different point. If this is the case, then perhaps the ideal solution is to develop systems that enable the use of multiple modalities in a synergistic manner in a single procedure. This is one rationale for the development of hybrid systems. Ideally, though, the hybrid system would be more than a combined gantry; the two modalities would ideally be synergistic in the target applications. Examples of this synergistic use are described below.

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PET/CT AND SPECT/CT

Among all the hybrid systems that have been explored, the combination of Positron Emission Tomography (PET) and x-ray transmission CT is perhaps the most mature and validated (see, e.g., [1-3]). PET is a powerful imaging modality whose main strength is the specificity of the targeting of the radiopharmaceuticals used. The most commonly used agent is ^{18}F-FDG, and the most common application is tumor detection and characterization, but other probes and applications are in use and many more are being developed. The localization of the PET agent can be so specific that the image consists of one or more bright regions is a field of low intensity. While this specificity can be powerful, it can make image interpretation difficult. Often, the radiologist needs anatomic information to accurately interpret the study, and the PET emission image provides few anatomical clues. CT is an ideal complement for the PET image, since CT can provide excellent anatomic images. One can use CT scans performed before or after the PET study, but image registration can be difficult, especially in the thorax and abdomen where any registration has to account for deformable motion.

Since the annihilation photons resulting from the positron decay can be absorbed or scattered before they reach the detectors, and this attenuation is different for different projection paths, proper reconstruction and accurate quantitation requires correction for attenuation. Classic PET systems accomplish this by measuring, in addition to the emission data, transmission data with which attenuation correction can be performed. Acquisition of transmission data can be time consuming, and noise in the transmission measurements negatively impacts the final PET images. The data quality of the transmission measurements is not sufficient for good anatomic CT images.

PET/CT is an elegant solution to this problem. Registration of the PET and CT images is more straight-forward. The anatomic CT and biochemical PET data can simultaneously be used to make the diagnosis. Further, the CT data can be used for attenuation correction, eliminating the need for attenuation measurements with the PET detectors and thereby shortening the exam time.

The rationale for SPECT/CT [4-6] is similar. While attenuation correction in SPECT is more difficult than in PET, use of CT data for attenuation correction in SPECT make this problem only slightly harder.

XRAY/MR

Both x-ray fluoroscopy and MRI are powerful tools for guiding interventional procedures. MRI has exquisite soft tissue contrast, excellent three-dimensional visualization, the ability to image in any scan plane, and the possibility of providing physiological information. X-ray fluoroscopy provides high spatial resolution (> 2 lp/mm), real-time (30 frames/sec) two-dimensional projections with excellent contrast for guidance and placement of catheters, stents, platinum coils and other metallic devices. A hybrid imaging platform could take advantage of the strengths of each system to provide optimum image guidance and ongoing assessment of treatment during a number of procedures.

Recently, x-ray/MR hybrid systems that provide access to both x-ray fluoroscopy and MR during a single procedure have been described [7-11]. The simplest consist of separate MRI and x-ray systems with a coupled patient transport apparatus [7-9]. This design strategy was driven by the use of relatively standard x-ray components (*e.g.* image intensifiers and rotating anode x-ray tubes) and by the need to ensure minimal impact of one system on the other. As a result, use of these systems requires moving the patient (and the table) tens of feet between two separate gantries. Moving the patient is a somewhat time-consuming and cumbersome approach, leading to potential risk and loss of image registration. It would also invariably lead to less than optimal use of the modalities, since one may be reluctant to move the patient repeatedly. We have integrated an x-ray fluoroscopy system directly into the bore of an interventional MRI unit [10-11]. This truly hybrid system allows access to both MRI and x-ray fluoroscopy with no patient motion. This required investigation of a number of technical issues, most notably the effect of the strong magnetic field on the operation of an x-ray tube. We've been using a fixed anode tube with the anode-cathode axis aligned with the direction of the magnetic field. Studies of the effect of the field on electron trajectories and focal spot size were performed, and validated the use of such tubes in high magnetic fields. To detect the transmitted x-rays, we're using an indirectconversion flat panel x-ray detector capable of fluoroscopic imaging. With these components, we have successfully conducted both animal and human studies.

OTHER HYBRIDS

A number of other hybrid systems have been proposed or are under study. The combination of CT and x-ray fluoroscopy is being explored for interventional imaging. The combination of MR and PET could have high impact in functional neuroimaging. The advantage of MR over CT in this hybrid (i.e. MR/PET vs. CT/PET) is MRI's superiority in imaging neuroanatomy, as well as the further benefit that could come from MR spectroscopic information. In molecular imaging, the combination of optical fluorescence imaging with CT may be beneficial if CT can provide anatomic clues for the fluorescence information. The combination of optical fluorescence and PET is already being used for molecular imaging in small animal models.

CONCLUSIONS

Medical imaging has made enormous strides, and now comprises a number of modalities, each with important strengths but also some limitations. Continued research will undoubtedly lead to further improvements in these modalities, but the unique way in which each probes the object will still cause the combination of modalities to be highly desirable. This leads to the prediction that hybrid systems will become more prevalent in coming years.

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