IBEX technology applied to diagnostic radiography

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Abstract

Medical X-ray imaging technologies are an important field which bring enormous benefits to millions of patients every year. IBEX materials contrast technology has the potential to deliver additional information to a clinician in diagnostic imaging with no extra dose to the patient. Standard Digital Radiography (DR) provides absorption contrast images which lose energy-dependent information related to the materials present in the sample; for example, tissue and bone composition. IBEX technology gathers this information from a single exposure, giving access to materials information whilst not compromising a high resolution, high quality conventional absorption contrast radiograph. The additional materials information can, for example, help distinguish between dense or thick soft tissue and thinner bone, or lead to familiar diagnostic measurements such as areal Bone Mineral Density (aBMD) being extracted from a standard DR system.

Introduction

Standard Digital Radiography (DR) systems provide absorption contrast images (radiographs) which are clinically useful in a wide variety of clinical presentations/ diagnoses but which show only overall absorption contrast. Energy-dependent information, which relates to the different materials in the sample, is lost.

Dual Energy X-Ray Absorptiometry (DEXA) or other multi-spectral X-ray techniques [1-3] use multiple energy measurements gathered by multiple exposures or by complex energy-sensitive detectors to access energy-dependent information. These techniques can provide specialist measurements of, for example, areal bone mineral density (aBMD) which is usually interpreted to give fracture risk estimates for a particular patient.

IBEX Multi-Absorption Plate (MAP) technology recovers energy-dependent absorption information from standard DR with minimal modification to the equipment. In typical indirect DR detectors, all deposited photon energy is integrated into a single intensity value, so information about how different X-ray energies are attenuated is lost. IBEX technology restores this information by spatially modulating the X-ray spectrum (and hence the X-ray beam energy) periodically across a detector, removing the need for specialised systems or multiple scans to acquire it. Since the information is captured in a single exposure, the potential for motion artefacts is greatly decreased and the overall dose to the patient can be reduced. Being a slim, passive element, the MAP can be easily added to existing X-ray equipment.

Algorithms have been developed in order to interpret this modulated image to give high quality, high resolution, diagnostic outputs, as well as generating separate "materials contrast" images. Using this information we are able to assess changes in tissue/bone composition. Thicker or denser tissue and thinner bone can therefore be distinguished. All this is achieved at minimal cost in terms of patient dose, system complexity, and computation time.

An IBEX enabled system

Figure 1 schematically shows a conventional X-ray imaging system, with the IBEX MAP included. The source delivers a spectrum of energies which are attenuated by the sample according to the material types and thicknesses in the beam path. The resulting absorption contrast image is collected using a flat-panel detector or a line scanner. Each pixel integrates over all the energies incident on it, returning a single value of intensity.

However, absorption contrast alone is not a reliable method for direct deduction of material properties. For example, an image may contain grey-levels within regions of predominantly bone attenuation which are the same as in some areas of pure tissue (consider, for example, the radiograph shown in Figure 3 in the Results and Discussion section).

Introduction of the IBEX MAP enables energy-dependent information to be recovered, which allows a materials image to be constructed. With suitable training of the system, it is possible to generate measures showing the relative amounts of soft tissue and bone at a given location.

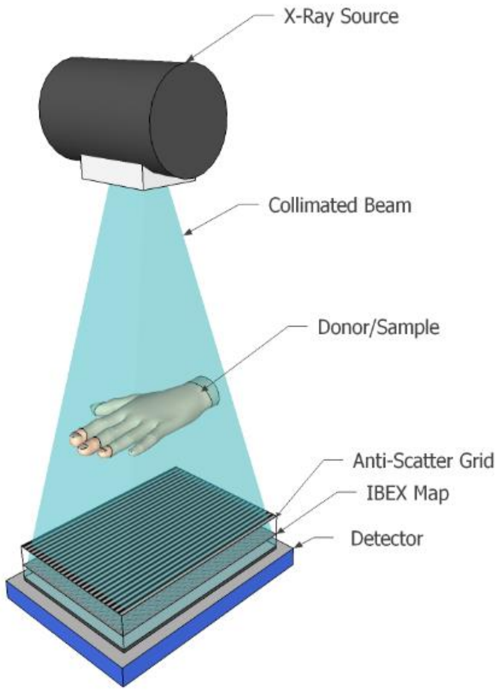

Figure 1: Standard DR configuration, with the addition of the IBEX MAP, for measurements on cadaver donor parts. Not to scale.

IBEX technology

The absorption of X-rays by a material depends on the material type, its thickness, and the energy of the X-rays (Eq. 1):

$$I(E) = I_0(E)\exp(-\mu(E)t) \qquad \text{Eq. 1}$$

where $I(E)$ is the intensity incident on the detector after the sample, as a function of energy, E; $I_0(E)$ is the incident intensity, as function of energy, in the absence of a sample; $\mu(E)$ is the linear attenuation coefficient of the material as a function of energy, and t is the material thickness.

The X-ray imaging detectors in most widespread use are based on silicon with a scintillator screen in front. These are a rapid, relatively inexpensive and reliable way of imaging large areas; however they integrate all energies in each pixel – and therefore do not record spectral information. Without spectral information, there is no direct way to determine both material and thickness from the signals obtained. Spectroscopic detectors are available; they are generally slower than silicon detectors, more expensive and are not usually available in large areas.

IBEX's MAP technology overcomes these limitations. In a small region of the detector covered by different thicknesses of the MAP structure, we may extract multiple measurements relating to different beam attenuations and therefore different energy ranges.

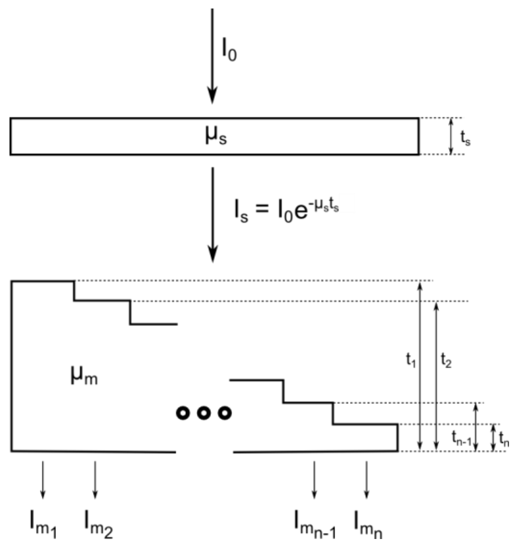

Figure 2: Impact of an IBEX MAP structure on an incident monochromatic X-ray beam.

$$I_{m_1} = I_0.\exp(-\mu_s t_s - \mu_{m_1} t_{m_1})$$

$$\vdots \qquad \text{Eq. 2}$$

$$I_{m_n} = I_0.\exp(-\mu_s t_s - \mu_{m_n} t_{m_n})$$

Figure 2 shows the effect of an IBEX MAP structure, formed of a variety of thicknesses of an attenuating material, on a monochromatic beam. Eq. 2, which is derived from Eq. 1, describes how incident X-rays (intensity I_0) are attenuated by a sample with linear attenuation coefficient, μ_s. The attenuated X-rays then pass through the IBEX MAP. In a system with a polychromatic X-ray beam (e.g. from a tungsten target source) the detector forms an image of the integral of I_m over an X-ray spectrum which is modified locally by the IBEX MAP (known) and the sample (to be analysed).

It is the combination of measurements with varying MAP attenuation over a few neighbouring pixels which then results in measures which are sensitive to changes in material in the sample, not just its overall absorption. This allows the construction of an image based on materials contrast across the sample, rather than absorption contrast. In turn, it is now possible to calculate material thickness, which is impossible with only absorption information. The results can be presented in a variety of ways, depending on the requirements of the application.

In addition to the material information described above, a high resolution conventional absorption contrast image is delivered as part of the process. This is achieved by a tuned filter which removes the MAP modulation from the image without compromising the diagnostic quality.

Experiment

Several measurements have been taken on cadaver donor parts using typical clinical doses on a GE VMX Plus conventional mobile radiography system fitted with a standard TFT detector (Rayence 1417) and an appropriately-focused anti-scatter grid (Figure 1). The IBEX MAP was fitted between the anti-scatter grid and the detector scintillator. The source-to-detector distance was fixed at 115 cm and the donor part was placed as close to the detector as possible.

DR images were acquired of the lower arm and wrist of the cadaveric donor with X-ray tube kV and mAs values appropriate for clinical assessment (Table 1).

The absorption contrast images were post-processed to remove the effect of the MAP and recover high quality, high resolution diagnostic radiographs.

Table 1: Exposure conditions for the diagnostic radiography measurements.

Donor body part	X-ray kV	X-ray mAs	Detector air kerma / µGy
Lower arm	60	1.6	2.8
Wrist	60	0.5	0.9

The IBEX materials analysis algorithm was trained to recognise the signatures of bulk soft tissue and bone within each absorption image, which was modulated by the MAP structure. These were used to optimise the contrast within the materials images subsequently reconstructed. The materials signatures allow soft tissue and bone to be modelled as independent materials, enabling images to be produced showing only what is different from one material or the other. The scale of the remaining contrast indicates the scale of the material difference.

Results and Discussion

Figure 3 and Figure 4 show the high quality radiographs where the effect of the MAP has been removed, along with images showing materials contrast compared to bulk soft tissue, i.e. highlighting bone and the outlines of the skin envelope.

Comparing the absorption contrast radiographs with the IBEX materials contrast images in Figure 3 and Figure 4, the contrast between the bone and tissue regions has increased significantly.

In this work, the units of difference from the nominated material are arbitrary. Future work will allow this measure to be mapped to areal Bone Mineral Density (aBMD), providing a direct, clinically useful diagnostic output.

Figure 3: Lower arm. Top: High resolution IBEX radiograph. Bottom: IBEX materials difference image (difference from bulk soft tissue).

Figure 4: Absorption contrast radiograph (top) of the wrist together with the materials difference image (bottom) relative to bulk soft tissue.

Images may also be generated which show the materials contrast compared to bone. Enabling the effect of a given material to be removed from the image gives a clearer view of what is left, which could, for example, render a tumour more visible. Such "decluttering" is particularly helpful when the image is quite crowded with multiple different structures overlapping or incorporated with the radiograph (e.g. a radiograph of the chest).

Conclusions

The application of IBEX MAP technology and analysis to medical radiography creates a series of images from a single acquisition, showing contrast between materials while retaining a high quality, high resolution radiograph. The IBEX materials contrast images provide additional useful information to a clinician which was not available previously. These images are obtained at standard clinical dose levels for radiography, and avoid the need for an additional DEXA scan.

IBEX technology also offers the possibility of decluttering an image by stripping out the effect of one component (e.g. removing the bone structure).

Future work will allow mapping the materials difference information to such quantitative diagnostic measures as areal Bone Mineral Density (aBMD).

Acknowledgments

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References

1. Johnson, Thorsten R. C., *et al.*, eds. *Dual Energy CT in Clinical Practice*. **201** (1). Springer, Berlin (2011).
2. Lu, Guang Ming, *et al.*, "Dual-energy CT of the lung." *American Journal of Roentgenology* **199.5_supplement**, (2012) S40-S53.
3. Van der Sluis, I. M., *et al.*, "Reference data for bone density and body composition measured with dual energy x ray absorptiometry in white children and young adults." *Archives of disease in childhood* **87.4** (2002) 341-347.

IBEX technology is protected by a number of patent applications worldwide. See www.ibexinnovations.co.uk for the latest information.

