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Dual-modality imaging with a ultrasound-gamma device for oncology

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ABSTRACT

Recently, dual-modality systems have been developed, aimed to correlate anatomical and functional information, improving disease localization and helping oncological or surgical treatments.

Moreover, due to the growing interest in handheld detectors for preclinical trials or small animal imaging, in this work a new dual modality integrated device, based on a Ultrasounds probe and a small Field of View Single Photon Emission gamma camera, is proposed.

1. Introduction

In the field of in vivo imaging several morphological and functional modalities are utilized in order to gather as much information as possible about a disease or organ. The Nuclear Medicine imaging techniques, i.e. Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT), are classified as functional imaging techniques while UltraSound (US), Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are classified as morphological imaging techniques with an exception when contrast agent are utilized.

One of the most appealing progress in the field of the in vivo imaging is the realization of dual-mode detectors able to combine different imaging techniques. The correlation of complementary imaging modalities has an increasingly important role for the improvement of the diagnostic results and the treatments of a great number of diseases (Townsend, 2008), as example it could be useful to distinguish a benign lesion from a malignant one.

Dual-modality devices as SPECT/CT and PET/CT (http://www3,; http://www.,) are daily employed in hospitals all around the world. These techniques provide high-resolution anatomical information (coming from CT), correlated with the functional ones (coming from SPECT or PET), and they are aimed to improve the disease localization and to help the treatment planning for radiation oncology or surgery (Hasegawa and Zaidi, 2006).

However, in spite of the high images quality, the scientific community is debating about the high effective dose to the patient, in particular from PET/CT system, representing an indicator of the cancer stochastic risk. An evaluation of Lifetime Attributable Risk (LAR) of cancer incidence associated to the radiation dose is done by Huang et al. (2009). The authors suggest a clinical justification of the examination and a detailed research about the dose reduction.

Moreover, the physicians have recently shown a growing interest for hand held detectors or dedicated devices for small organs, that could be used, as example, in pre-clinical trials or in small animal imaging. In this way, the US technique is the most useful anatomical technique for hand held detector. Moreover it is a widely used diagnostic modality thanks to its non ionizing nature. Furthermore, US technique needs a short time for acquisition, it has a good spatial resolution and especially it has a relative low cost. On the other hand, the US images quality is operator dependent, as consequence the expansion and upgrading of the diagnostic US imaging has highlighted the need to have US practitioners with more qualified performances in order to reduce errors and malpractices.

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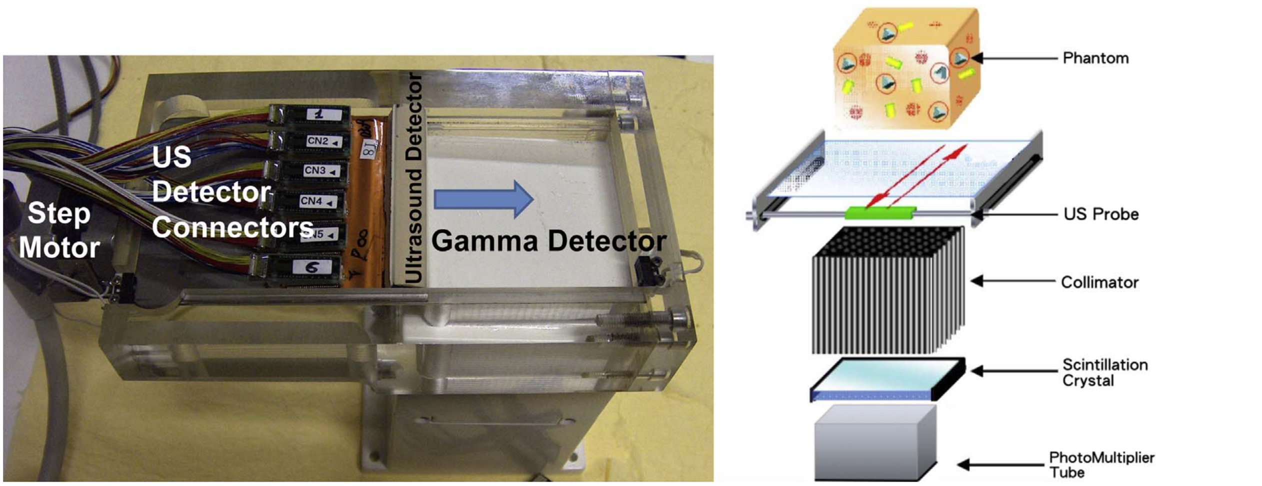

Fig. 1. Integrated US-gamma system. From left to right: the step motor employed to move the ultrasound detector on the gamma detector FoV; the US detector wires and the relative connectors used as electronic readout; the US detector and finally the gamma detector. The arrow indicates the motion direction of the US probe (left). Block diagram of the integrated US-gamma device and its parts (right).

About the functional technique that could work in tandem with US, the SPECT modality is the best candidate thanks to the possibility to realize small/medium size detectors, the high efficiency, as a function of the used collimator and the absence of magnetic field that strongly influences the electronic readout system and is a limitation for patients with metallic prosthesis and/or pacemaker. US and SPECT can greatly contribute to the diagnostic efforts of the physicians because they are noninvasive techniques and because they are complementary each other for the diseases diagnosis (Walibe et al., 2003). US does not provide any functional information while SPECT is able to detect changes in the organ function amplifying the significance of anatomic changes as found in ultrasonogram.

For these reasons, several projects use US/SPECT devices to study different diseases. These techniques are applied to diagnose Coronary Artery Disease (CAD) by Huang et al. (2009). The authors show the feasibility of the multimodality registration of two-dimensional (2D) and three-dimensional (3D) cardiac US images with the cardiac SPECT ones, obtaining anatomical and functional information simultaneously. The proposed method demonstrated that the registration of cardiac US and SPECT images is able to provide a more accurate and powerful tool for the CAD diagnosis.

The dual modality approach is also used by Casara et al. in order to investigate the efficacy of an imaging protocol for the exploration of patients affected by hyperparathyroidism. The work demonstrate that an accurate preoperative evaluation of the disease can help the surgeons providing useful information and allowing minimally invasive and time-saving surgery (Casara et al., 2001).

Another application is described by Patel et al. (2010): the US technique is combined with a SPECT/CT in order to improve the localization of a single adenoma in parathyroid, the principal cause of primary hyperparathyroidism. Since the surgical approach is rather invasive, an accurate localization allows to limit damages, removing only the adenoma. In spite of the diagnosis improvement, the use of a detector with a size close to the one of the analyzed organ can facilitate the diagnosis, with an unquestionable advantage in terms of radiation dose reduction for the patient.

In this context, some devices based on dual modality US-single photon emission (SPE) probe have been advanced. An example is reported by Okur et al. (2014): a device for guided needle biopsy of sentinel lymph node is proposed. The gamma imager is a mini gamma camera (about 2 in. size) producing 2D image and an optical pointer is used to coordinate the movement of the US and gamma devices which are not integrated. Differently, Rogers and Wainstock (1974) presented an ultrasound-guided gamma-ray probe for ocular melanomas detection. In this case a 2D image of the tumor is provided by a brightness US scan (B mode) while the gamma detector, based on a 11/16 in. diameter by 1 mm thick Sodium Iodide (NaI:Tl) crystal is working just as a counter and not as an imager.

So, to go towards this imaging scenario, in this work a new dual modality integrated imager is proposed. It is based on a US probe and on a small Field of View (FoV) SPE gamma camera. This last device is planned with a cerium doped lanthanum tribromide ($LaBr_3$:Ce) scintillation crystal allowing to obtain 2D information (Cencelli et al., 2010; Meo et al., 2009). The compact gamma detector, with its high spatial resolution, is a good candidate to assemble an hand held device that works in tandem with a US probe. Furthermore the FoV of both detectors are comparable (50 mm side) facilitating the realization of the dual modality image.

2. Materials

2.1. Ultrasound detector

The linear US detector, from HITACHI, is a piezoelectric probe with reduced overall dimensions ($70 \times 12 \times 7\,mm^3$) and 192 crystals. It is mounted on a shifting bed, moving across the FoV of the gamma detector, in order to get the 3D US C-mode acquisition. The US detector is customized by Lefa Industry (http://www.lefa.it) in order to reduce the back suppressor thicknesses, with the aim to minimize the Source Collimator Distance (SCD), as an advantage for the gamma detector spatial resolution. A dedicated software has been developed in order to synchronize the step motor, used to move the US probe, with the image acquisition procedure. In Fig. 1 the integrated US-Gamma system is reported. The test object is placed on the top of the overall detector in order to guarantee the acoustical coupling with the US probe.

2.2. Gamma detector

The gamma detector is based on a Hamamatsu H10966-100 MOD8 Multi Anode Photo Multiplier Tube (MA-PMT) (Hamamatsu h8500c technical data-sheet, 2005) that is coupled to a $50 \times 50 \times 4\,mm^3$ continuous $LaBr_3$:Ce scintillation crystal (Brillance380 data-sheet). The scintillator has been selected to obtain high energy and spatial resolution in order to reach a good match with the high spatial performances of the US probe. H10966-100 MOD8 MA-PMT is equipped with an enhanced quantum efficiency photocathode (38% @380 nm) and 8 stages of metal channel dynodes. The 64 outputs from the MA-PMT anodic plane are independently read out by a Field Programmable Gate