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Original paper

Design and development of a dedicated portable gamma camera system for intra-operative imaging

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ABSTRACT

Purpose: We developed a high performance portable gamma camera platform dedicated to identification of sentinel lymph nodes (SLNs) and radio-guided surgery for cancer patients. In this work, we present the performance characteristics of SURGEOSIGHT-I, the first version of this platform that can intra-operatively provide high-resolution images of the surveyed areas.
Methods: At the heart of this camera, there is a 43×43 array of pixelated sodium-activated cesium iodide (CsI(Na)) scintillation crystal with 1×1 mm^2 pixel size and 5 mm thickness coupled to a Hamamatsu H8500 flat-panel multi-anode (64 channels) photomultiplier tube. The probe is equipped with a hexagonal parallel-hole lead collimator with 1.2 mm holes. The detector, collimator, and the associated front-end electronics are encapsulated in a common housing referred to as head.
Results: Our results show a count rate of ~41 kcps for 20% count loss. The extrinsic energy resolution was measured as 20.6% at 140 keV. The spatial resolution and the sensitivity of the system on the collimator surface was measured as 2.2 mm and 142 cps/MBq, respectively. In addition, the integral and differential uniformity, after uniformity correction, in useful field-of-view (UFOV) were measured 4.5% and 4.6%, respectively.
Conclusions: This system can be used for a number of clinical applications including SLN biopsy and radiopharmaceutical-guided surgery.

1. Introduction

A key prognostic factor in patients with early stage cancer is the metastases status of the regional nodes draining the primary tumor [1–3]. The metastasis to local and distant nodes helps identifying the choice of therapy, tumor staging, and patient's outcome. Sentinel lymph node (SLN) concept and lymphatic mapping [4,5] is considered the current standard of care in which the cancer patient is injected with either blue dye (followed by direct vision during surgery) or radiopharmaceuticals for scintigraphic mapping with a gamma camera and intraoperative identification of sentinel lymph nodes (using a gamma probe). The SLN is defined as the first node of lymphatic drainage from the primary tumor [6,7].

While conventional gamma cameras are still used for pre-operative lymphoscintigraphy, their geometry and performance are not optimized for detecting lymph nodes. The use of portable gamma cameras and intra-operative probes is justified by the close proximity of the detector to a tumor or node during surgery which leads to increased solid angle and enhances the detection efficiency.

In recent years, portable gamma camera systems have received much attention to perform SLN lymphoscintigraphy [8]. The main applications of such dedicated small-sized intra-operative imaging systems are the detection of SLNs in breast cancer and melanoma, and functional imaging of the thyroid and parathyroid glands [9,10].

Recently, several portable gamma camera designs have been proposed for SLN surgery in breast cancer patients [9,11–15].

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Trotta et al. [16] developed a gamma camera consisting of a pixelated CsI(Na) crystal array with 2.45 mm pixel pitch coupled to a position-sensitive photomultiplier tube (PSPMT) and a parallel-hole collimator for intra-operative imaging. They achieved a spatial resolution of 2.5 mm full-width at half-maximum (FWHM) and 204 cps/MBq sensitivity. Olcott et al. [13] constructed a portable gamma camera system based on H8500 square PSPMT coupled to an NaI(Tl) crystal array. The detector was equipped with a high-sensitivity parallel-hole collimator with 1.3 mm hole size, 0.2 mm septa thickness, and 2 cm collimator thickness. The system has a spatial resolution of 1.6 mm (FWHM at 1 cm), sensitivity of 135 cps/MBq, and energy resolution of 12.3%. Fernández et al. [17] designed and developed a mini gamma camera based on a continuous CsI(Na) crystal block with dimension of $50 \times 50 \times 4.6\ mm^3$, H8500 PSPMT readout, and 2 mm single-pinhole collimator. The characterization of the system was reported as 1.3 mm intrinsic spatial resolution (camera without collimator), 13% energy resolution at 140 keV, and 54 cps/MBq planar sensitivity for the 2 mm pinhole collimator at 4 cm [18]. Knoll et al. [19] reported the characterization of a hand-held gamma camera based on semiconductor with a cadmium-zinc-telluride (CZT). A parallel-square-hole collimator with 2.16×2.16 mm hole size and 0.3 mm septa was attached to the detector. This system has an intrinsic energy resolution of 5.2%, an integral and differential uniformity of 5.8% and 3.8%, respectively, and a system sensitivity of 237 cps/MBq with low-energy high-resolution (LEHR) collimator.

The aim of this study is to report the design and performance characterization of SURGEOSIGHT-I, a portable gamma camera system that we recently developed at the Research Center for Molecular and Cellular Imaging, Tehran University of Medical Sciences. The performance parameters of the SURGEOSIGHT-I were evaluated according to the NEMA NU1-2007 standard [20].

2. Material and methods

2.1. Camera design

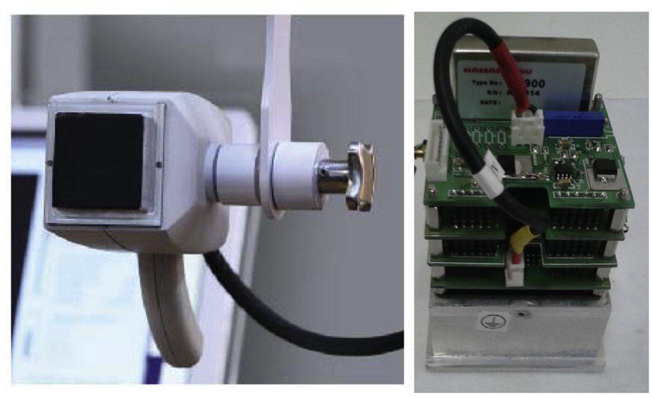
2.1.1. Detection system

The SURGEOSIGHT-I (Fig. 1(a)) detector module consists of a 43×43 array of CsI(Na) scintillator (Hilger Crystals, UK) with pixel dimensions of 1 mm × 1 mm × 5 mm (1.2 mm pixel pitch) optically glued to a H8500C PSPMT (Hamamatsu Photonic Co., Japan) with $49 \times 49\ mm^2$ active area. A low-energy general-purpose parallel-hole lead collimator with 1.2 mm hexagonal holes, 18 mm thickness, 0.2 mm septal thickness, and total dimension of $50 \times 50\ mm^2$ was attached to the front side of the crystal. The detection system including crystal, PSPMT, and electronic boards are placed in housing, shielded by at least 3 mm lead (Fig. 1(b)).

2.1.2. Electronic readout

Dedicated electronics were designed and developed for data acquisition and processing that were placed inside the head or trolley. The trolley is equipped with an adjustable arm (4 degrees of freedom) to provide the required motions around the patient, conveniently (Fig. 1(a)). The readout system consists of one high-voltage (HV) board, a resistive network board, and two amplifier boards which are placed inside the camera head (Fig. 1(b)). Data acquisition board is placed inside the trolley. Moreover, an all-in-one computer is mounted on the trolley for further signal processing, data calibrations, image generation, and displaying the images of the surveyed area. The HV board generates regulated −900 V as bias voltage of the PSPMT. The gain uniformity in 64 channels of PSPMT at this bias voltage is shown in Fig. 2. Relative differences between areas of maximum and minimum pulse height values are 39%.

(a)



(b)

Fig. 1. The SURGEOSIGHT-I system (a), and the system head and front-end electronics (b).

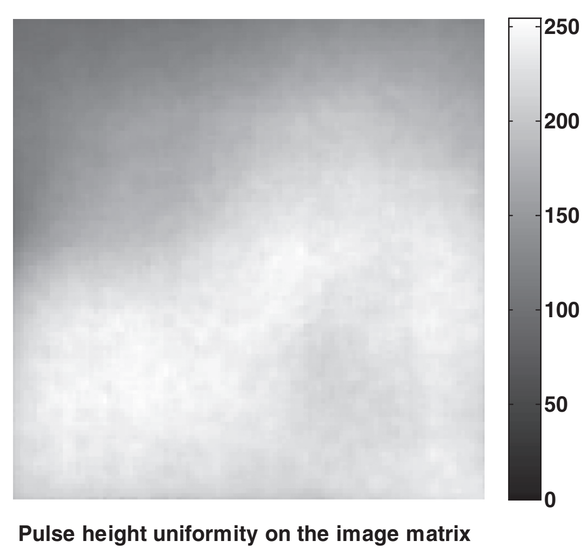


Fig. 2. Image of pulse height uniformity in −900 V as bias voltage. Relative differences between areas of maximum and minimum pulse height values are 39%.

The PSPMT produces 8×8 anode signals which are then summed in rows and columns using a simple resistive network (shown in Fig. 3(a)) to reduce the number of electronic channels.