Characterization of Performance of a Miniature, High Sensitivity Gamma Ray Camera

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***Abstract*--A compact, hand-held gamma camera with excellent intrinsic and extrinsic performance has been developed for the rapid identification and localization of the sentinel lymph node during the surgical staging of cancer. A goal for this device is an image acquisition time of five seconds to allow the surgeon to easily search for points of interest without excessive motion blurring. The camera comprises a 5x5 cm^2 field of view NaI (Tl) pixellated crystal array, a high sensitivity (2.0 cm thick) hexagonal parallel-hole collimator, a position sensitive photomultiplier tube (PSPMT), and a novel highly multiplexed electrical readout. The good intrinsic energy resolution (12.3±2.6%) resolution, extrinsic sensitivity (5 cps/μCi with 24% energy window) and extrinsic spatial resolution (1.6+/-0.02 mm at 0.5 cm) facilitate rapid identification of a hot node.**

I. Introduction

COMPACT hand-held gamma cameras can potentially be used to help localize the sentinel node in breast or skin cancer staging biopsy [1]. The sentinel lymph node (SLN) is defined as the first lymph node to drain the primary tumor basin. The SLN can be mapped by using a sulphur-colloid radiotracer labelled with Tc-99m that is injected near the primary tumor site along with a blue dye. Approximately 500 μCi to 1 mCi of tracer is injected around or underneath the primary tumor, with 500 nCi to 2 μCi of activity accumulating in the sentinel lymph node after it drains through the lymphatic channels [2]. Most of the activity stays within the injection site, and drains slowly down the lymphatic channels. Currently, non-imaging intra-operative gamma ray probes are used to locate the SLN using a collimated detector and an auditory signal to represent activity detected. The non-imaging probes play three roles in sentinel node biopsy. First, they are used to locate the SLN and guide its extraction. Secondly, they can be used to measure the activity of the extracted lymph node. Lastly, they can be used to scan for any other hot lymph nodes that should also be extracted for biopsy [3]-[5]. However, the learning curve for the gamma probe technique is significant, the procedure is time consuming and invasive, and there are certain situations where node identification is difficult or impossible. In this paper we describe the characterization of intrinsic and extrinsic performance of a small hand-held gamma camera we are developing to help resolve some of these issues.

II. Materials

The hand-held gamma camera consists of a 5 cm x 5cm x 2 cm hexagonal parallel hole collimator with 1.3mm hole size and 0.2 mm septa coupled to a 29x29 pixellated 1.5x1.5x6 mm^3 NaI(Tl) scintillation crystal on a 1.7 mm pitch coupled to a flat panel multi-anode Hammatsu H8500 Position Sensitive Photomultiplier (PSPMT), which is read out using a Symmetric Charge Division PCB Circuit. Approximately 3 mm of lead shielding was wrapped around the collimator and the scintillation crystal. A sentinel lymph node phantom consisted of a small spheres ranging in size from 3 mm to 8 mm in diameter arranged in a circular pattern that was drilled in a disk of plastic Lucite. Previous studies used an array of 2x2x3 mm^3 LSO crystals [6].

III. Methods

A. Intrinsic Camera Performance

The intrinsic energy gated flood histogram of the camera is generated by calculating and histogramming the 2-D spatial distribution of the center of the light cone created for each gamma ray interaction within the scintillation crystal from flood Co-57 (122 keV) flood irradiation. After segmenting the 2-D histogram, events can be binned to individual crystals. The spectral properties of each crystal can be extracted and analyzed. The properties that are of interest are the photopeak location, the photopeak energy resolution, and the photopeak counts. Intrinsic spatial resolution is measured by stepping a collimated beam of Co-57 gamma rays across the face of the scintillation crystal. Events are binned to individual crystals and plotted as a function of known spot location. The FWHM of the resulting trapezoid response is the measure of the resolution of a single crystal in the array. The counts in neighboring crystals give an indication of inter-crystal scatter and unrelated background events.

B. Extrinsic Camera Performance

We measured the sensitivity (the number of counts per second / μCi) and the resolution (FWHM of the point spread function (PSF)), as a function of depth and collimator thickness.

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C. *Sphere Phantoms*

A simulation of the sentinel node environment was made using sphere phantoms submerged in water placed next to a bottle filled with 250 µCi of Tc-99m (see Fig. 1) representing the injections site. The spheres were filled with a concentration of 64 µCi/cc Tc-99m water. The activity per sphere ranged from approximately 1 µCi for the smallest to 16 µCi for the largest. A warm background of 120 µC was added to the water to simulate the potential contamination from the tissues or the injection site that could occur from an invasive surgical procedure.

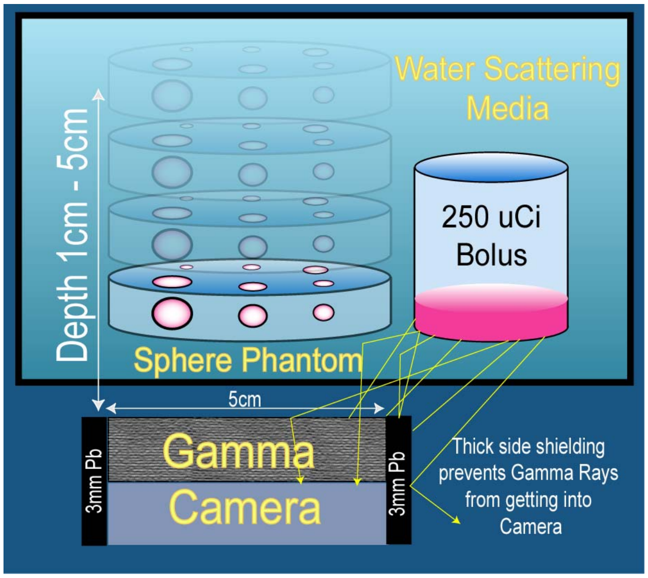

Fig. 1. Sphere phantoms were placed at different depths in a water scattering medium. A bottle was placed just outside the field of view to simulate the injection site. A 1:250 contrast ratio was chosen to represent the smallest sphere to injection site activity ratio.

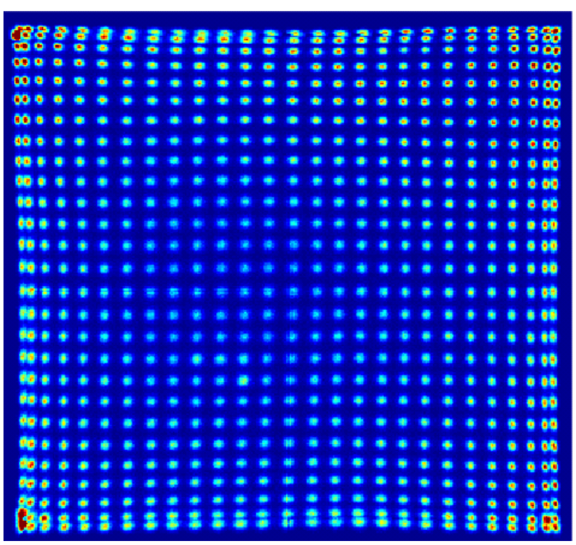

Fig. 2. Energy gated 2-D Flood histogram for a 10 µCi Co-57 point source flood. Only 27x27 crystals are resolved out of a 29x29 array.

IV. Results

A. *Intrinsic Flood Histogram*

27x27 distinct crystals were resolved from the 2-D flood histogram (see Fig 2). Examining the energy spectrum of the edge crystals, there is a dual photopeak due totwo edge crystals mapping to same location on the PSPMT. It is possible to resolve an extra row of crystals through the use of energy gating. These edge crystals have a significantly degraded energy resolution and were not used because of the potential for injection site activity to create hot edge artifacts.

B. *Energy Resolution*

The NaI(Th) crystal array has a good average energy resolution of 13.2 +/- 2.2% Some of the corner crystals have energy resolution > 20%, but do not significantly affect the imaging performance (see Fig. 3). The energy resolution is high enough so that one may use a narrow energy window to remove scatter and lead x-ray escape contamination while

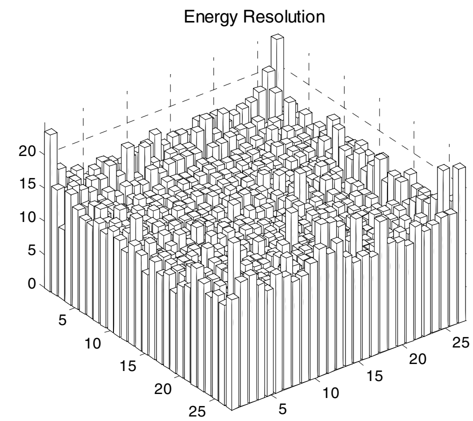

Fig. 3. Energy Resolution for each of the crystals in the 27x27 crystal array.

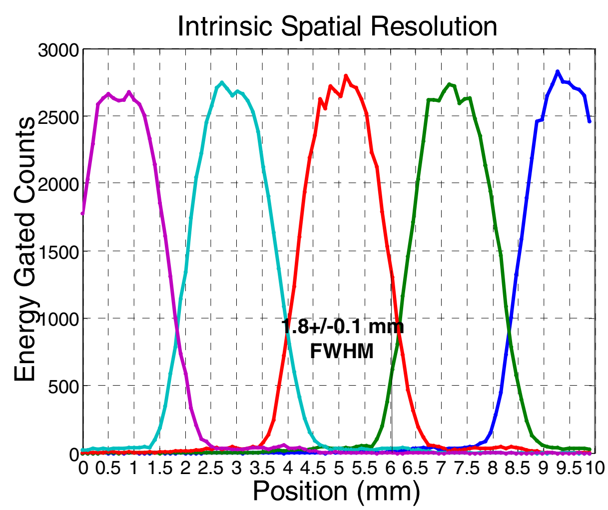

Fig. 4. Intrinsic spatial resolution is measured by stepping a collimated point source across the face of the crystals. The spot size was approximately 500 um, and the FWHM of the trapezoid is 1.8 +/- 0.1 mm.

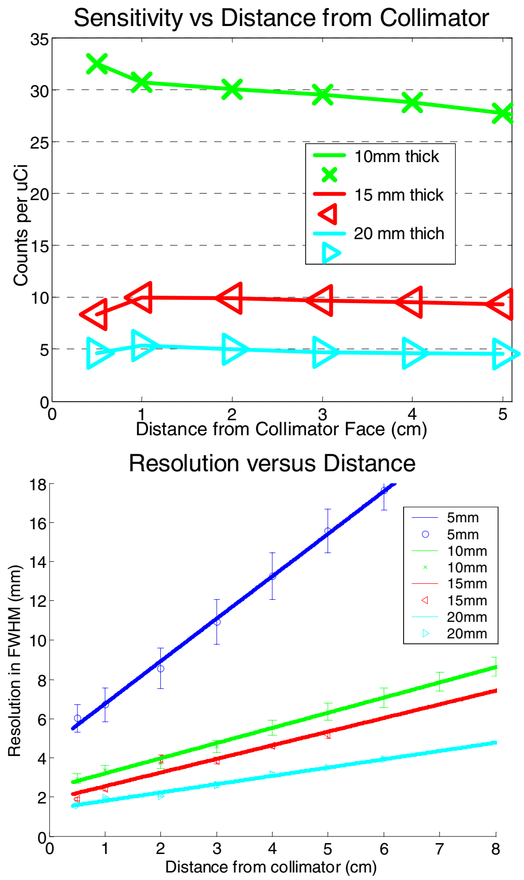

Fig 5. Sensitivity and Resolution as a function of distance for several different collimators of varying thickness. The camera has approximately a 5 cps/uCi sensitivity and a 1.6 +/- 0.02 mm FWHM resolution at 0.5 cm for a 20 mm thick collimator.

maintaining high counts.

C. Intrinsic Spatial Resolution

The resolution was measured for 5 crystals that were right of center in the array. The measured 1.8 +/- 0.1 mm FWHM resolution corresponds well with the 1.7 mm pitch of our crystal array (see Fig. 4). Because with gating there is low intercrystal crosstalk, and the crystals in the flood image do not fully overlap, there is the potential to utilize even smaller crystal sizes than the 1.5 mm. Unfortunately because of the 200 µm reflector thickness, we would have a significant a reduction in sensitivity if we moved to much smaller than 1.5 mm which would be unacceptable for this hand-held application.

V. Extrinsic Performance

The extrinsic perfomance was measured with several collimators of varying thickness and a 67 uC Co-57 point source. The point source was stepped at several distances from the collimator and the sensitivity and resolution were extracted from the data. We chose the 20 mm collimator because it gave the best resolution and sensitivity tradeoff (see Fig. 5). If we are trying to image a 3 mm lymph node with 1 µC of activity and a 5 second exposure window then approximately 6-7 counts per pixel will land in a small group of pixels. Even though this is a small number of counts, there is sufficient statistics to be able to detect a node.

VI. Sphere Phantoms

The sphere phantoms were measured in a water scattering media (see Fig. 1) with and without a warm background. In a hand-held camera, motion blurring (see Fig. 6) is a problem compared to fixed gamma cameras or those that have been attached to an articulated arm [1]. The fixed gamma cameras do not have the flexibility of the non-imaging intra-operative probes and of hand-held gamma cameras. Other research groups are addressing the motion blurring and small field of view of the hand-held camera by attempting to use motion sensors to tile the image into a large synthetic field of view [7], [8], but the technique may be unfeasible at <2 mm spatial resolution. If the probe can be held against the skin, or if the surgeon scans slowly, then images much like the phantom experiment in Fig. 7 will be produced.

Image processing significantly enhances the raw count images by bringing out weaker smaller nodes in the presence of statistics limited noise and saturation from hot active features. The exposure duration is the most significant factor in node detection ability of the camera. Long exposure duration is impractical because it would require the surgeon to hold the camera very still for a long time. While 3 mm nodes can be detected in all the 10-second images, it is probably more practical to use a 5 second exposure time (see Fig. 7). The 3 mm node would be detectable 2.6 cm away from the camera in 5 seconds, which probably makes this camera quite useful for locating SLN. In the presence of background

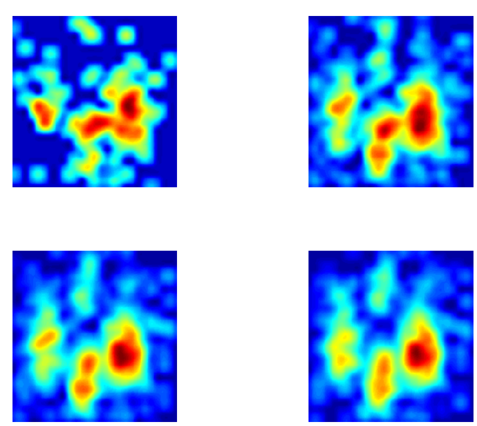

Fig. 6. Holding the sphere phantoms over the collimator simulates hand-held operation. At resolutions bellow 4 mm there is noticeable motion blurring that makes it hard to make out the small spheres. The exposure time for this sequence is approximately 3 seconds per frame.

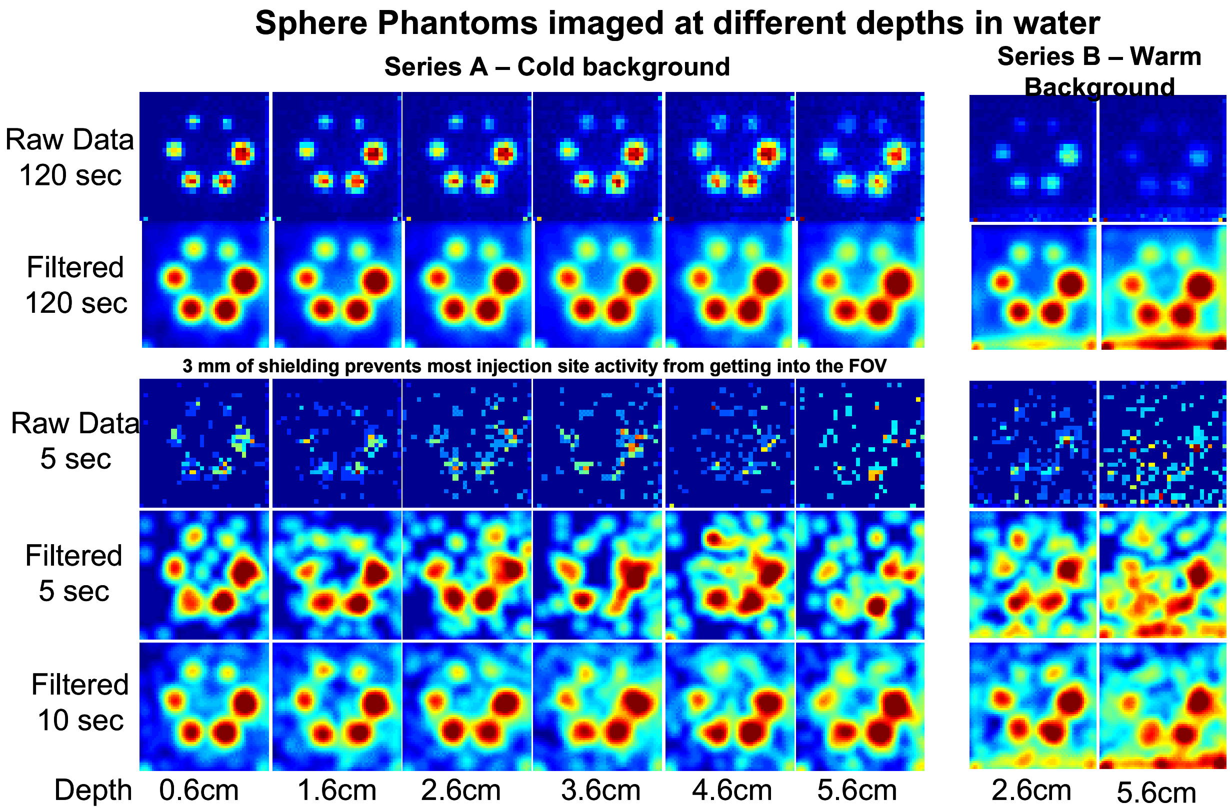

Fig. 7. The sphere phantom is imaged at different depths in water with and without the presence of background. The filtering algorithm is a combination of square root compression, 3x3 Gaussian filtering, bi-cubic image resize x8 , and a upper 70% threshold. The exposure duration is noted as the number of seconds. High statistics 120-second frames are compared to 5-second and 10-second frames. The injection site, which is just out of the field of view, does not significantly contaminate the image.

contamination it is more difficult, but still possible to resolve the majority of nodes in the phantom at a depth of 2.6 cm.

VII. Conclusions

This hand-held scintillation camera has good intrinsic and extrinsic performance for sentinel node biopsy applications. Pixellated scintillation crystals provide good spatial resolution, sensitivity, and energy resolution. The gamma camera was able to image spheres at 2.6 cm in 5 seconds with approximately a 1 μCi total activity.

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