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Hybrid handheld gamma-ultrasound prototype for radioguided surgery: initial results

Abstract: We have witnessed impressive advances in preoperative imaging of cancer and the development of dual-modality scanners. However, there is a need for a scanner with functional and anatomical imaging capability suitable for surgical settings and radioguided surgery. The current paper introduces a handheld gamma-ultrasound scanner prototype and illustrates the initial result of testing its very first version. The result of the testing was promising and encouraging in continuing the further development of the prototype.

Keywords: handheld scanner, gamma-ultrasound scanner, radioguided surgery

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1 Introduction

Cancer is the leading cause of death worldwide, with nearly 13 million new cases diagnosed and 7.6 million deaths each year [1]. This challenge has been a driving force for researchers and companies to do intensive basic research and technological developments in cancer to manage this disease effectively [2]. As a result, we have witnessed the advent of novel techniques and technologies.

Development of anatomical modalities computed tomography (CT) and magnetic resonance imaging (MRI), together with functional modalities positron emission tomography (PET), and single photon emission computed tomography (SPECT), has been of the remarkable advances in the field which are now a common practice in preoperative imaging of cancer. A further milestone in cancer imaging technologies has been reached by integrating anatomical and functional imaging modalities. In today's modern medicine,

PET/CT, SPECT/CT, PET/MRI scanners are inevitable tools in cancer diagnosis. These techniques, however, are not applicable in intraoperative settings because of their bulkiness and the special requirement of the room they are used in. As a result, visual inspection or audio-based monitoring, for the most part, has been the predominant method in intraoperative procedures [3].

Recently, handheld gamma cameras have started to come into play in surgical scenarios to provide surgeons with real-time nuclear image inside the operating rooms. These cameras are designed to image small and superficial structures and come in handy in sentinel lymph node studies [4]. Although their small size makes them suitable for radio-guided surgery, the lack of structural information in their acquired images is a significant drawback of these scanners. To address this unmet clinical need, we introduce a handheld gamma-ultrasound (US) scanner that makes it possible for the surgeon to see both anatomy and function of their target. The scanner's compact size can ideally suit surgical settings and is expected to give the user flexibility and manoeuvrability required for radio-guided surgery.

2 Methods and Materials

We designed (SolidWorks, Dassault Systèmes, France) and 3D-printed (Formlabs, USA) an adaptor case to combine a US transducer (General Electric, United States) and a handheld gamma camera (Crystal Photonics GmbH, Germany) (see Figure 1).

The case was designed such that it allowed to test the main feature of the proposed concept to combine US imaging and nuclear imaging technologies. The case included an aluminium plate that served as a mirror for the US waves. Detail of the concept used to integrate the two imaging technologies using the US mirror can be found here [5].

The US part of the prototype was a linear transducer of a 9L US probe of the LOGIQ E9 machine. We first opened up the probe case, then transferred the transducer and its electronics into the prototype case. The inside of the case was

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then filled with gelatine to provide a traveling medium for the US wave.

Figure 1: Adaptor case to combine ultrasound technology and nuclear imaging technology

The gamma camera of the prototype was the Cadmium Zinc Telluride (CZT) detector of an interventional handheld gamma camera. This camera has a 40×40 mm² field of view and is optimized for detecting radioactive sources that emit 40keV-250keV gamma photons. We used a lead plate to cover part of the scanning window of the camera and used 10×40 mm² of it. Throughout the nuclear imaging, the camera was attached to the case and held by a supporting arm.

As the gamma photons reaching the CTZ detector had to pass through the aluminium plate, we needed to measure the photon attenuation effect of the plate. To this end, a Co-57 point source (Eckert & Ziegler GmbH, Germany) was placed under a 7-mm-thick polymethyl methacrylate (PMMA) plate and scanned using a standard SLN probe (HiSens, Crystal Photonics GmbH, Germany). Then we replicated the scanning with the aluminium plate placed between the source and the probe. Then, the recorded photons of the two setups were compared. The Co-57 point source had a diameter of 3.45 mm and an activity of 33 kBq at the time of the experiment.

It was also required to assess the degrading effect of the aluminium plate on the quality of the US image taken by the prototype. To this end, we scanned a standard US phantom (model 044, CIRS, USA) by our prototype and a normal US probe of the same model. Then, the obtained results from the two scanners were compared in terms of the depth of penetration (DOP) and distance accuracy.

After the quality testing of the two imaging parts of the prototype, we scanned a custom-built gamma-US phantom. To create this phantom, we put 50ml gelatine powder in a transparent bowl and added 450ml of hot water to the powder. We stirred the mixture continuously for about 5 minutes until all the powder completely dissolved. Then, we placed the ball target with a diameter of 30mm into the phantom. The ball also had a tube connected to it that was used to fill the ball with the radioactive source. We then kept the phantom in a refrigerator

for 2 hours to congeal. Then the phantom was filled with Tc-99m and scanned by the prototype. In the end, the acquired US and gamma images were fused in the MATLAB2019a (MathWorks Inc., USA) environment.

Table 1: Result of distance accuracy testing of our prototype and a normal US probe.

US Frequency (MHz)	Vertical Direction (mm)		Horizontal Direction (mm)	
	Our prototype	US probe	Our prototype	US probe
6	18.8	18.6	12.8	12.3
8	18.7	18.5	12.8	12.4
9	18.8	18.6	12.7	12.3

3 Results

The results of US phantom scanning revealed a desirable performance of the prototype despite the expected negative effect of the aluminium plate on its performance. The prototype detected all the 5 DOP targets, down to 12 cm in phantom, seen by the normal US probe. Results of the distance accuracy test of the prototype also showed a good agreement with that of a normal US probe at three frequencies (see table 1).

Although the performance of the US part of the prototype was promising, the attenuation effect of the aluminium plate on gamma photons was significant. In the setup used in the current study, we realized that the plate attenuated 32% of the photons. To compensate this attenuation effect, the prototype needed extended time to record enough photons by its CTZ detector and present a good quality image of the target being scanned.

The custom-made phantom and result of scanning it by the prototype are given in figure 2.

Figure 2: The custom-made gamma-US phantom (left) and the result of its scanning by the gamma-US scanner prototype (right)

To do the image fusion, the image acquired by the CZT detector was input to MATLAB, and one slice, the central slice matching the central cross-section of the ball target, was extracted and extended through the entire depth of the phantom. The resultant image was then fused with the US image acquired by the prototype. During the fusion process, the ball surface was used as a qualitative marker to put the two images together and get and estimate the fused gamma-US.

4 Conclusion

The current paper presents the initial result of testing of the first prototype of a handheld gamma-US scanner. The aim was to build the first version of the prototype case to put the US transducer and a CTZ detector together so as to tests the main feature of the scanner.

The results of testing the scanner in the US imaging part was promising. However, the effect of the aluminium plate on gamma photon attenuation was significant. One potential solution to mitigate this effect is to use a very thin aluminium plate, such as an aluminium film, as a US mirror. This way, the significant part of the gamma photons can pass through and reach the gamma camera, improving the overall quality of the gamma imaging.

For the current proof of concept study, fusion of the images was done by superimposing the two images using the ball surface as the marker. Although a sophisticated technique should have been applied, the visual superimposing of the two images was sufficient for our investigation as proof of concept study. This is, however, one limitation of our study. Therefore, the fusion of the functional and anatomical images acquired by our prototype through the image fusion standard process is the subject of our future study. We're also planning to replace the aluminium plate used in the current study with a thin

aluminium film to reduce its attenuation effect on gamma photons reaching the detector. On the whole, this initial result encouraged us to continue developing this scanner and introducing it as a tool in radio-guided surgical procedures.

The vision of this development is to introduce a handheld hybrid scanner for radioguided surgery. The scanner's small size should allow it to fit easily in surgery rooms. A surgeon can hold the scanner easily with one hand while using the other hand to grasp a surgical tool like a biopsy needle. The fusion of images won't need any sophisticated tracking systems. In the modern surgery that robots are increasingly coming into play, the scanner could ideally be held and controlled by a robotic system.

Author Statement

Conflict of interest: Authors state no conflict of interest.

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