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SmartCAM: An adaptive clinical SPECT camera

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Abstract

An adaptive pinhole aperture that fits a GE MaxiCam Single-Photon-Emission Computed Tomography (SPECT) system has been designed, built, and is undergoing testing. The purpose of an adaptive aperture is to allow the imaging system to make adjustments to the aperture while imaging data are being acquired. Our adaptive pinhole aperture can alter several imaging parameters, including field of view, resolution, sensitivity, and magnification. The dynamic nature of such an aperture allows for imaging of specific regions of interest based on initial measurements of the patient. Ideally, this mode of data collection will improve the understanding of a patient's condition, and will facilitate better diagnosis and treatment. The aperture was constructed using aluminum and a low melting point, high-stopping-power metal alloy called Cerrobend. The aperture utilizes a rotating disk for the selection of a pinhole configuration; as the aluminum disk rotates, different pinholes move into view of the camera face and allow the passage of gamma rays through that particular pinhole. By controlling the angular position of the disk, the optical characteristics of the aperture can be modified, allowing the system to acquire data from controlled regions of interest. First testing was performed with a small radioactive source to prove the functionality of the aperture.

1. INTRODUCTION

Single-Photon-Emission Computed Tomography (SPECT) is a clinical imaging procedure that images radiotracer distributions within a patient.¹ SPECT imaging is a functional imaging modality that images the physiological activity of the body as opposed to anatomical structures within the body. The most common applications of SPECT are cancer imaging and cardiac perfusion imaging. In SPECT imaging, a patient is injected with a radiopharmaceutical that is then distributed throughout the body with differential uptake in the target tissues. As gamma rays are emitted, a fraction of them will pass through an aperture made of a gamma ray attenuating material. The photons that pass through the aperture and strike a scintillation crystal may be absorbed and visible light is emitted and measured by an array of photomultiplier tubes. The location of the photon interaction can be calculated, and in this manner a projection image of radionuclide distribution can be produced. Multiple projections are collected at different angles around the patient and can then be reconstructed into a 3D tomographic image representing the spatial distribution of the radiopharmaceutical using one of several reconstruction algorithms. The vast majority of clinical SPECT systems utilize parallel-hole collimators. Using parallel-hole collimators

results in projection images that lack distortion and enables image reconstruction using traditional filtered back projection (FBP) reconstruction methods.²

We designed an adaptive pinhole aperture for a GE MaxiCam 400 SPECT system³ that is capable of changing configurations based on imaging needs as determined by image information, patient history, and clinician input. The parameters of a pinhole aperture includes pinhole size, pinhole location relative to the patient and the detector face along all axes, the angular position of the camera around the long axis of the imaging area, and the number of pinholes open at any given time. Ultimately the goal of our work is to allow the system to automatically make adjustments to the aperture to image a region or regions of interest with extra sensitivity or resolution (see Figure 1).^{4,5} These adjustments and the resulting image reconstructions will, in turn, provide clinicians with highly specific and accurate information about the imaged regions of interest. The ability of this aperture to reconfigure based on patient data makes this system an adaptive system that can accommodate many different geometric and pathological conditions of the various patients being imaged. This system presents several challenges, notably that the camera must be reconfigurable under computer control to adapt itself to the given imaging task.⁶ In addition, tomographic image reconstruction relies on a very accurate understanding of the physical parameters of each imaging configuration, so the designed aperture must be capable of setting the imaging parameters in an accurate and reproducible manner.⁷

2. APERTURE DESIGN AND CONSTRUCTION

Our design consists primarily of two pieces, a disc of Cerrobend containing pinholes of many different sizes and configurations, and a conical body which serves to block all light not passing through the desired pinhole. Figure 2 shows the layout of the aperture design. The disc is mounted off center compared to the body of the aperture, and it covers a pinhole-selection slit completely. This design allows only a small strip of the pinhole disc to be in view of the camera face, and rotating the disc about its center will change which pinhole is used. Different pinhole configurations at different angular positions on the disc can be achieved by rotating the disc. Thus, a single stepper motor is needed to change the configuration of the aperture.

Cerrobend is used as the attenuating material in the aperture. However, Cerrobend is not ideal choice for a structural element because it is a soft metal alloy. We therefore designed an aluminum shell that serves both as a mold for the cerrobend core and also as a rigid frame that can be bolted to the camera. The framework is composed of seven individual pieces of aluminum welded together as indicated in Figure 2. The first component of the aluminum shell is a baseplate that serves as the connecting point of the aperture and the GE Maxicam system. Welded to this baseplate are two concentric partial cones; one of the cone pieces has a slightly smaller radius than the other such that one fits inside the other with space between to allow a low temperature casting pour to form a high stopping power Cerrobend core. Two face plates are also welded to the tops of each cone piece so as to form a closed structure with an open slit that allows for the passage of gamma rays only at one angular position on the disc. An L-shaped frame to house the motor and provide a mounting point for this shell and the rotating pinhole disc are welded to the side. The final element of the aluminum

frame is the shell of the pinhole disc. Cerrobend is not mechanically strong or reliable, and is thus poured into CNC-machined cavities in an aluminum disk that provides structural support to the Cerrobend.

Our initial design for the pinhole disc was a flat plate, with a lip on the side so that molten Cerrobend could be poured in and cast. However, we found that the Cerrobend separated from the aluminum plate in the middle due to differential thermal expansion, and did not meet the flatness criterion desired. Test results discussed later in this paper show that even with the pinhole disc being slightly out of the design specification, the adaptability requirement was satisfied. However, in order to address the casting imperfection, a modified aluminum disk has been designed that is more tolerant of Cerrobend alloy casting characteristics. We anticipate that the redesign will entirely resolve the issue, at which point further tests will be performed, including acquisition of multiple angular views of test objects to test rigidity during camera rotation.

3. TESTING

Testing of the aperture was performed primarily with a small Cobalt-57 source, which emits 122 keV gamma rays. We mounted the aperture to the MaxiCam system, and positioned it such that the field of view was looking down at a ruled, flat surface. The source was placed on the ruled surface in the field of view of the aperture, and images were acquired with the MaxiCam 400AC camera head, with a digital waveform-capture data-acquisition unit from CAEN⁸ and in-house developed software. Data were acquired as the source translated through the field of view of the pinhole, and as the open pinhole was translated along the face of the camera. In this way we were able to assess the performance of the aperture for various pinhole configurations and source positions. Figure 3 shows the system response acquired as described above, for various configurations of the test setup. Quantitative measurements were intentionally omitted from this figure, as the purpose of this test was to qualitatively assess the adaptability and imaging performance of the aperture and camera system. More testing to accurately measure the system response and assess observer performance will be performed in the near future.

4. RESULTS AND CONCLUDING REMARKS

As the testing has demonstrated, our aperture utilizes adaptable pinhole configurations to change its imaging characteristics, such as field of view and sensitivity. The sensitivity of the aperture drops as object being imaged moves away from the optical axis, due to the fact that a realizable pinhole must have non-zero thickness and therefore some degree of vignetting. Oblique projections also cause blurring in the crystal due to the fact that gamma rays may interact at any depth within the crystal. This causes a parallax effect that can only be partially compensated for by using iterative reconstruction methods and including in a forward model of the image formation.⁹ Furthermore, with a traditional fixed pinhole or parallel-hole collimator, objects at the edges of the FOV will be imaged to the edge of the detector, where intrinsic resolution is lower than at the center. By adjusting the position of the pinhole along the face of the camera, we should be able to optimize the system to minimize all three of these potentially negative effects.

5. FUTURE WORK

Improvements to both the aperture and the MaxiCam test system are currently under way. Ultimately our goal is to integrate the camera system and the aperture such that a fully automated SPECT scan utilizing the full orbit of the camera head and the entire range of pinhole configurations is possible.

A hybrid digital and analog data acquisition system was designed for the MaxiCam and is currently being utilized for all testing of the aperture. The camera uses an Anger resistor network to estimate position of interactions, the output of which consists of four analog signals. These signals are input into the CAEN waveform digitizer. We then use custom software to analyze the digitized signals and calculate estimated event properties such as position and energy. Currently the system is functional, and was used to acquire testing data on the aperture. However, in the future we plan to digitally read signals from each PMT in the camera head, rather than relying on the Anger logic, which can then be used with estimation techniques to improve the intrinsic resolution of the camera. Maximum-likelihood methods will be used for estimating photon properties. The aperture itself is undergoing work to correct the aforementioned deformation of the pinhole disc. This will allow work to continue on testing the aperture as well as the acquisition system. Work will also continue on the automated adaptability of the aperture so that the aperture can be integrated with the MaxiCam camera and control software to form SmartCAM, a system to perform adaptive clinical SPECT acquisitions.

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Figure 1.
Illustration of adaptive aperture adjustment to track a region of interest as gamma camera revolves around the subject.

Figure 2.
Exploded view of aluminum frame

Figure 3.
System responses for different point source locations and pinhole configurations.