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DETECTION AND EVALUATION OF CAESIUM-137 POINT SOURCE USING SILICONE PHOTOMULTIPLIER SENSOR

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By

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Chair: Prof. Ts. M. Iqbal b. Saripan, PhD
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Gamma camera or also known as scintillation camera is a typical device used for image acquisition in the field of medical imaging. It is usually used as a non invasive technique to view and diagnose a patient by the reconstructed images of a human body. Current gamma camera technology typically constructed using photomultiplier tubes (PMT) is considered to be costly and space consuming. In addition to this, it also operates at a very high voltage and measurements can be affected by the existence of magnetic field. Recent research on photon detection has resulted to the introduction of silicone photomultiplier (SiPM) which operates at low voltage and insensitive to magnetic field. Generally, SiPM is a photo sensor that has great potential in replacing PMT in a gamma camera. However several elements of SiPM need to be considered. The aim of this research is to develop a gamma camera with SiPM sensor technology. Several important parameters need to be identified in modelling the gamma camera. The parameters include on configuring the optimum SiPM High Voltage Bias (V_{bias}) value based on the sensor's temperature characteristic and the optimum operating distance. The research also focused in implementing the modelled gamma camera to reconstruct and evaluate the images from the experimental projection data. Several laboratory equipment and materials are used for the experiments in this research, including the Vertilon IQSP480 data acquisition reader, the Thallium doped Caesium Iodide (CsI(Tl)) crystal scintillation material, the SiPM sensor array SL4-30035 and others. The radioactive source Caesium-137 (Cs-137) is used for this research as a gamma emitting substance. Cs-137 is a common substance used for calibrating radiation equipments and radiation therapy. In addition to this, it also has a longer half life of over 30 years. Result and analysis from the experiments conducted have revealed that, the sensor bias voltage, V_{bias} of the SiPM needs to be set to 27.8 V at a stable operating temperature of 43 °C, in order for the sensor to only trigger in the presence of a radioactive source. Next, the radioactive source has to be placed within a 1 cm distance from the sensor to obtain the optimum measurements from the data

acquisition reader. The gamma camera modelled in this research is able to capture gamma ray energy projected to the SiPM sensor by accumulating up to 120 pC of charge in duration of 10 seconds. The sensor is able produce a spatial resolution of 26% at 662 keV. It also has a detection efficiency of 14%. At a distance of 1 cm, it is able to record 1542 photon counts upon exposure to a Cs-137 point source for 60 seconds. Furthermore, evaluation of the images reconstructed from the gamma camera has also revealed that the projection data pre-processing interpolation with Gaussian method is able to produce the highest pixel luminance and contrast value. Back Projection algorithm with Ram-Lak filter is also considered to be the most suitable technique to be applied for this gamma camera in reconstructing the image of a point source gamma emitting radioactive material. In conclusion, this research has successfully developed a gamma camera using SiPM technology that can perform a 12 mm x 12 mm scanning area. It is constructed with a 4 x 4 pixel SiPM sensor and a CsI(Tl) scintillation material with a thickness of 6.35 mm. The dimension of SiPM sensor which is generally smaller in sizes in comparison with PMT is suitable in producing a mobile and portable medical imaging device in the future
.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGESANAN DAN PENILAIAN TITIK SUMBER CAESIUM-137 DENGAN MENGGUNA PAKAI SENSOR SILICONE PHOTOMULTIPLIER

Oleh

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Kamera gamma atau kamera kerlipan cahaya adalah satu peralatan yang biasa digunakan dalam bidang pengimejan perubatan. Ianya digunakan sebagai peralatan yang tidak memberi kemudaratan kepada pesakit semasa teknik memperoleh imej pesakit untuk proses diagnostik. Teknologi kamera gamma pada ketika ini yang menggunakan photomultiplier tubes (PMT) boleh dianggap memerlukan kos yang tinggi untuk di hasilkan disamping menggunakan ruang yg besar untuk diguna pakai. Tambahan pula ia memerlukan voltan yang tinggi untuk di aktifkan dan bacaannya amat terkesan dengan kewujudan medan elektro magnet. Kajian terkini dalam bidang pengesanan cahaya foton telah memperkenalkan penemuan sensor silicone photomultiplier (SiPM) yang mampu beroperasi pada voltan rendah dan kurang sensitif pada kesan medan magnet. Ia mempunyai potensi besar bagi menggantikan PMT pada kamera gamma. Namun begitu, beberapa elemen pada SiPM perlu diambil perhatian khusus. Kajian penyelidikan tesis ini bertujuan untuk menghasilkan sebuah kamera gamma menggunakan sensor SiPM. Beberapa elemen penting pada SiPM perlu dikenal pasti untuk penghasilan sebuah kamera gamma. Elemen tersebut merangkumi konfigurasi voltan pincang (V_{bias}) SiPM menurut perubahan suhu pada sensor dan juga kedudukan terbaik jarak pemancar sinar gamma. Tambahan lagi, penyelidikan pada tesis ini juga telah mengkaji tahap keberkesanan kamera dalam menghasilkan imej-imej dari data-data eksperimen yang dijalankan. Beberapa peralatan digunakan dalam kajian eksperimen ini, termasuk alat Vertilon IQSP480 untuk merekod data, bahan penghasil kerlipan cahaya Caesium Iodide (CsI(Tl)), sensor SiPM SL4-30035 dan lain-lain lagi. Bahan radio aktif Caesium-137 (Cs-137) telah digunakan sebagai sumber panghasilan sinar gamma. Cs-137 adalah suatu bahan yang biasa digunakan bagi kalibrasi peralatan radio-aktif dan juga pada terapi radiasi. Tambahan lagi, Cs-137 mempunyai jangka hayat yang panjang, sekitar 30 tahun. Hasil kajian menunjukkan bahawa sensor SiPM pada kamera kerlipan cahaya ini perlu beroperasi dengan optimum dengan voltan V_{bias} 27.8 V pada kestabikan suhu

43 °C. Titik sumber Cs-137 perlu di letak pada posisi 1 cm daripada sensor bagi mendapatkan bacaan yang optimum, Kamera kerlipan cahaya yang di hasilkan untuk kajian ini mampu untuk mengesan bacaan sinar gamma yang dipancarkan kepada sensor SiPM sehingga cas 120 pC bagi pendedahan selama 10 saat. Sensor ini mampu menghasilkan resolusi spatial pada kadar 26% untuk sinar gamma 662 keV. Ia juga mempunyai 14% kadar pengesanan. Pada jarak 1 cm, ia mampu merekodkan 1542 cahaya foton apabila didedahkn kepada titik sumber radio-aktif Cs-137 selama 60 saat. Seterusnya, penilaian pada imej-imej yang terhasil daripada data kamera kerlipan cahaya ini telah menunjukkan teknik interpolasi Gaussian mampu menghasilkan imej dengan kadar luminans dan kontras terbaik. Imej ini perlu dihasilkan dengan mengguna pakai algoritma Back Projection bersama tapisan hingar Ram-Lak. Sebagai konklusi, kajian ini telah berjaya menghasilkan satu model kamera gamma menggunakan teknologi SiPM yang mampu mengimbas luas kawasan 12 mm x 12 mm. Kajian ini mengguna pakai sensor SiPM bersaiz 4 x 4 piksel dan bahan kerlipan cahaya CsI(Tl) berketebalan 6.35 mm. Sensor SiPM ini mempunyai saiz yang lebih kecil berbanding PMT. Justeru itu, ia sangat berpotensi bagi penghasilan peralatan mudah alih dan mudah gerak dalam menghasilkan imej pesakit dalam bidang perubatan pada masa-masa akan datang.

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LIST OF ABBREVIATIONS

APD	Avalanche Photo Diode
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
CsI(Tl)	Thallium Doped Caesium Iodide
FBP	Filtered Back Projection
MRI	Magnetic Resonance Imaging
NaI(Tl)	Thallium Doped Sodium Iodide
PET	Positron Emission Tomography
PMT	Photomultiplier Tube
SiPM	Silicone Photomultiplier
SPECT	Single Photon Emission Computed Tomography
V_{bias}	High Voltage Bias
V_{br}	Breakdown Voltage

CHAPTER 1

INTRODUCTION

1.1 Introduction

The field of nuclear medicine has been increasingly important at present day especially in assisting medical personnel in diagnosing patient for various types of diseases and performing radiation related treatment. The International Agency for Research on Cancer (IARC), an agency of World Health Organization (WHO) has reported that in 2012 alone, there are 14.1 million new cases related to cancer detected worldwide (American Cancer Society, 2015). Moreover, the report also mentions that during the same year, 8.2 million deaths occurred on cancer related patient. The report also suggests that the lack of access to treatment and early detection facilities has contributed to such figure in developed countries (American Cancer Society, 2015). Hence, medical equipment that can perform the task in imaging a patient body and performing treatment for early cancer detection is considered very important.

Several different imaging techniques with various known equipment have been developed for such purposes. Examples of imaging technique are Magnetic Resonance Imaging (MRI), ultrasound, x-ray radiography and nuclear medicine functional imaging. Nuclear medicine imaging includes the technique by Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT).

The medical imaging technique with SPECT is a common technique utilized in producing a patient's body image for cancer detection. SPECT machine is equipped with a gamma camera to detect the gamma radiation emitted by a patient injected with a radioactive substance. In addition to this, radiation therapy also relates to the use of gamma radiation such as in teleradiotherapy and brachytherapy. Gamma camera is also known as scintillation camera as it scintillates gamma radiation into low visible light photon.

Current gamma cameras are built with photomultiplier tubes (PMT) technology for photon detection. However, this conventional technology has been considered costly and space consuming (Acilu et al., 2012). Figure 1.1 illustrates an example of a SPECT machine. The typical specification includes having a weight of up to 300 kg and working voltage up to 150 kV (European Hospital, 2018).

Figure 1.1: Example of a SPECT machine
(Source: Global, Symbia Evo - Siemens Healthineers, 2018)

Nevertheless, recent research on photon detection and the capability of the avalanche photodiode (APD) has resulted to the introduction of silicone photomultiplier (SiPM). SiPM is a photo detector built with high gain capability and operates at low voltage (Roncali & Simon, 2011; Otte, 2006). Moreover, it is insensitive to magnetic field (Roncali & Simon, 2011; Otte, 2006). With these advantages, it has the potential in replacing the conventional PMT in gamma camera.

Current research in gamma camera SPECT system focuses on improving several areas in medical imaging procedure including on the gamma camera detection system, the electronics hardware and computing process. Meanwhile, the performance of each research improvement area of the gamma camera can be evaluated either by the resultant radio tracer distribution mapping, spatial resolution and also image quality.

Based on the information provided in this sub section, it is clearly shown that the development of a gamma camera with SiPM sensor is crucial and has potential in producing better medical imaging equipment in the future. Later chapter in this thesis will explain further on the methodology and analysis of the research outcome.

1.2 Research Problem

The technology related to imaging technique for patient medical diagnosis especially in SPECT system has been evolving in recent time. As mentioned previously, current gamma cameras are typically built with PMT technology for photon detection. However, this conventional technology has been considered costly and space consuming (Acilu et al., 2012). A typical SPECT machine can have a dimension of up to 100 cm x 78 cm x 300 cm and weight up to 300 kg to perform a coverage scanning area of 20 mm (Global, Symbia Evo - Siemens Healthineers, 2018). Hence, it is critical to produce a gamma camera that is more portable and consume less space in comparison to PMT gamma camera.

The technology using SiPM photo based sensor in gamma camera might be a suitable alternative.

Nevertheless, the application of SiPM as a gamma ray detector in a gamma camera might pose several challenges as SiPM in scientific and clinical research requires familiarity with its optical and electrical behaviour under varied environmental conditions (Slawomir S. Piatek, 2014). Parameters of SiPM needed to be taken into account during its operation includes the operating temperature, bias voltage and several others. Hence, it is critical to properly identify these parameters before SiPM can be utilized in a gamma camera.

Finally, in order to identify the performance of a newly developed gamma camera, several evaluation parameters can be used. These include the camera energy resolution, spatial resolution, sensitivity and others. However, to include more of the effects seen in clinical data, some performance standards call for a measurement of image quality such as the contrast ratio evaluation of the gamma camera (Daube-Witherspoon, 2014). Hence, it is important that a newly develop gamma camera be exposed to a gamma emission material to produce a projection data for image reconstruction and image quality evaluation.

1.3 Research Aim and Objectives

The main aim of this research is to develop a gamma ray detector for a gamma camera using SiPM photo based sensor with the capability of detecting and producing images from gamma ray projection of a Cs-137 point source element. In order to achieve the main aim, there are a few specific objectives that will be addressed in this thesis.

- The first objective of this research is to construct a functional gamma ray detector for a gamma camera by implementing a SiPM sensor. It should be able to perform a scanning area of 12 mm x 12 mm. The gamma ray detector should be fitted with a proper scintillation material in order to detect gamma radiation from a Cs-137 point source. The components selection is crucial as it dealt with detection of low visible light photon.

- Secondly, this research aims to identify the critical parameters required for the gamma ray detector. The parameters include on the SiPM operating temperature, the High Voltage Bias (V_{bias}) and the operating distance.

- The third objective is to perform post-processing analysis of the gamma projection data of a Cs-137 point source element. These includes on implementing several interpolation methods and applying filtering techniques from the detector projection data.

- The final objective of this research is to determine the performance of the SiPM gamma ray camera by evaluating the contrast ratio of the reconstructed images using the projection data taken from a Cs-137 point source element.

1.4 Scope of Study

Several important elements related to this research will be highlighted in this sub section. These includes on the research scope and limitation.

As highlighted previously, a gamma ray detector in a gamma camera functions by converting gamma ray photon to low visible light. Hence, for this research, a specific type of gamma ray emitting radioactive source typically used for clinical purposes will be utilized throughout the experimental procedure in this research. It is critical as the material is a control substance and access to it requires certain protocols and regulation. In addition to this, it will ensure that the experimental result and calculation done is consistent throughout the research.

For this research, the radioactive material Caesium 137 (Cs-137) will be used. Cs-137 is one of the most utilize radioactive source in nuclear medical field (Thoraeus, 1961). The material has an activity of 1 µCi which decay at a rate of 3.7×10^4 disintegrations per second (dps). Gamma ray released by Cs-137 is important to be analyzed as it offers several benefits in comparison with other lower energy gamma emitting elements. Cs-137 in particular has longer life time of 30 years compared to Tc-99m. Hence it does not need to be regularly produced during medical application and suitable for long experimental procedure.

Next, the research will also focus on acquiring projection data from a point source radioactive source rather than injecting the material to a particular phantom. This will enable a fix concentration of the gamma ray emission and constant comparison with the reconstructed images later. Furthermore, the SiPM photo sensor for this research gamma detector will use the product by SensL as it offers variety of light detection wavelength to match the specification of the scintillation material.

In addition to this, the experimental procedure will be conducted in a dark environment studio lab. This is to ensure that external light photon did not interfere during the experimental process. A constant dark environment can also be achieved.

Finally, the research will evaluate the gamma ray detector performance based on the contrast value of the reconstructed images. It is a typical evaluation parameter of images from a projected data from a radioactive point source. Moreover, several typical interpolation methods and filtering technique will be applied during the image reconstruction process.

1.5 Significant of Research

The outcome of this research will provide several important contributions towards the area of imaging with radioactive material, especially in the field of radiotherapy and nuclear medicine imaging system.

As mentioned previously, the recent introduction of SiPM photo based sensor offers several critical advantages in comparison with the PMT type of gamma ray detection material. SiPM is considered smaller in sizes, less weight and consume less space during its operation. Hence, it is hope that this research may pave the way in development of a more mobile and portable medical imaging device.

In addition to this, the research will provide the proper procedure in construction, development and evaluation of a gamma ray detector in a gamma camera with SiPM sensor. Nevertheless, other important elements need to be taken into account before proper medical imaging equipment can be introduced. These includes on the proper collimator design and also the embedded system of the device. These elements are suggestion on future research related to this study.

1.6 Structure of Thesis

This thesis covers several areas related to the research in developing a gamma ray detector for a gamma camera with SiPM. This thesis will consist of five main chapters.

The first chapter of the thesis will cover the introduction of the research. It includes on the general explanation on current situation of imaging technique with radioactive material in the field of medical imaging. Next it highlights the importance of the research and the research objectives.

The second chapter touches on the basic elements related to the research. This includes on literature review related to a construction of a gamma ray detector for a gamma camera. For examples, the gamma ray emission from radioactive material, basic gamma camera components and also general technique on image reconstruction from a gamma camera projection image.

Next, chapter 3 elaborates on the methodology in all related experiment with regards to modelling a gamma ray detector with SiPM sensor.

Finally, chapter 4 and 5 discuss and finally conclude the outcomes of the research. It also tabulates all the results from the experimental work done in the methodology section. The rest of the thesis is attached with appendices related to the research.

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