Southeast-Asian J. of Sciences Vol. 4, No. 2 (2016) pp. 109-120

THE APPLICATION OF PENELOPE PROGRAM ON BREAST IMAGING

Nguyen Anh Duy and **Ly Anh Tu**

Faculty of Applied Science, Bach Khoa University, VNU, HCM city
268 Ly Thuong Kiet St., Distr.10, Ho Chi Minh City
email: lyanhtu1@gmail.com; ng.anhduy89@gmail.com

Abstract

Breast cancer is the second most common disease in the world and is also the most common cancer in women. Mammography method is considered the gold standard in detecting tumors in diagnosis and treatment. In addition, tomosynthesis imaging method has been researched that opens a new advance in breast cancer diagnosis. Therefore, mammography equipment needs to achieve high accuracy in recording the details are extremely small size. The main content of this report is the application of simulation programs PENELOPE photon transmission via any materials associated with the creation PENEASY in mammography images can be applied in the design of the actual device.

Introduction

Breast cancer is the most common cancer in the world and the most popular cancer in women. There are approximately 1.67 milion new cases of cancer which are diagnosed in 2012 (25% of all cases of cancer). This cancer is also popular in both developed regions (794,000 cases) and developing regions (883,000 cases). Breast cancer ranks as the fifth leading cause of death from cancer in general (522,000 cases) and it is also the most common cause of death from cancer in developing regions (324,000 cases). In the more developed regions, this is the second cause of death (198,000 cases) after lung cancer [1].

In Vietnam, although it is not enough on medical conditions, however, Vietnam has a low proportion of breast cancer with around 23/100,000 inhabitants

Key words: PENEASY, PENELOPE, Breast cancer, diagnosis and treatment, tomosynthesis imaging method.

compared to approximately 120/100,000 population developed countries such as Australia and the United States. In developed countries, this ratio was kept stable or tends to decline. However, in Vietnam, this disease is growing to become leading cancer [2].

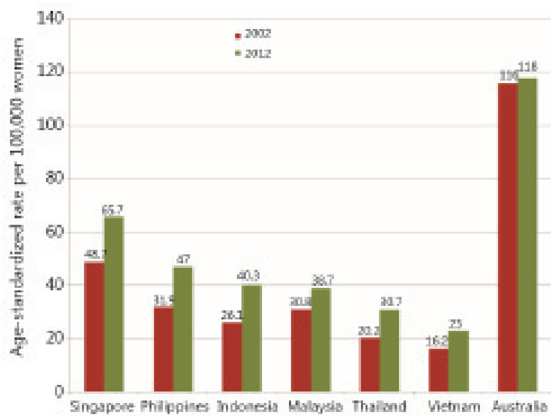

Figure 1: The diagram shows the ratio of disease in Vietnam compared to other Southeast Asian countries and Australia [2]

Therefore, early detection for timely treatment, reducing the risk of death is necessary. There are several methods for the diagnosis of breast cancer as ultrasound, magnetic resonance imaging, diagnostic cytology, sampling via biopsy specimens and surgical, etc. In these ways, mammography is used for the most common method that is considered to be the gold standard in the diagnosis of breast cancer [3]. Besides, following with the advantages of science and technology, tomosynthesis imaging has been studied in order to increase efficiency in the diagnosis of breast cancer that mammography is typically undetectable.

The study and evaluation need to be calculated carefully before applying into real practice. PENELOPE is the simulating program based on Monte Carlo method to simulate the transport of photons, electrons, and positrons in arbitrary material systems [4], combined to PENEASY [5] is a subroutine to simulate X-ray images. The results of this simulation could be used for the manufacture of real equipment.

Breast cancer

Breasts are the part of the body's chest or belly protruding nipple of mammal, and specifically at the case of feminine as functional dairy to produce milk for children. Breast is covered by skin and each breast has one nipple surrounded by areola. Areola color from pink to dark brown, hairless, and has several sebaceous glands. A Larger mammary gland in breast milk secretion. There are many lobes, each with 10-20 breast milk ducts to conduct milk from lobes to a nipple and each separates vent pipe. The majority of a breast is connective tissue, adipose tissue (fat) and Cooper's ligaments.

Breast cancer is a malignant disease appeared in the cells of the breast tissue. These cells often arise from the ducts or lobules in the breast, which can then spread in the tissues or organs and other parts of the body.

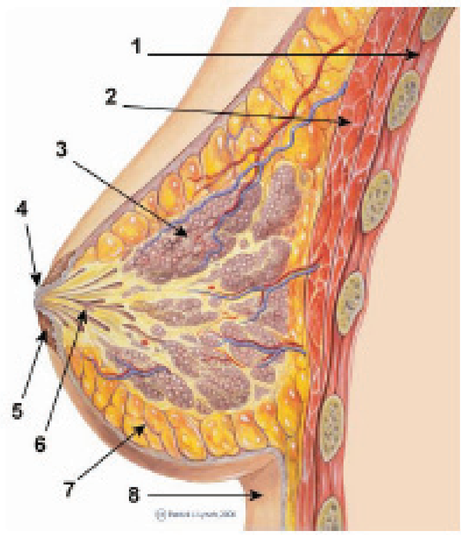

Figure 2: The section of breast in women: 1. Ribs, 2. Large chest muscle, 3. Lobes, 4. Nipple, 5. Areola, 6. Milk ducts (breast), 7. Adipose tissue, 8. Skin.

Most of the breast cancers are detected by the patient when they noticed a change in the mammary gland. Most commonly it is a tumor or a hard spot on the painless thickening in the breast, or it may be because doctor discovered through a routine health care visits.

The following properties of malignant tumor suggestions:

- Hard
- Not getting hurt
- Heterogeneous, unknown shore
- Stick to skin on the breast or chest wall, hard cell.
- Stretched nipples
- Bleed

Mammography

Mammography is an X-ray technique especially for breast used to support

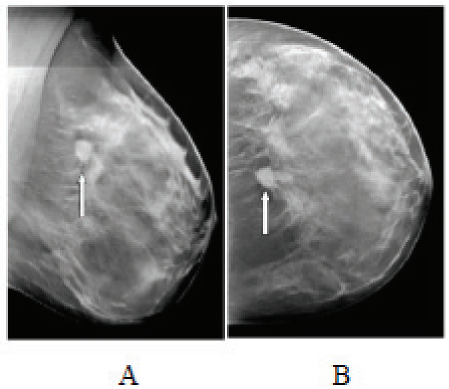

Figure 3: Tumors in two directions: A. Medio-lateral oblique (MLO) and B. Cranio-caudal (CC) [6].

the diagnosis of breast diseases in women. It is because this method is low cost, low radiation dose and sensitivity in recognizing the early stage detection of breast cancer, especially with the microcalcifications and structural deformation of the breast. The differences in morphology between tissue and tumor tissue generally require the application of a special X-ray equipment to optimize detection of breast cancer. Besides, the recognition of small calcifications in the breast is also important because small lime is one of the first cases of breast cancer.

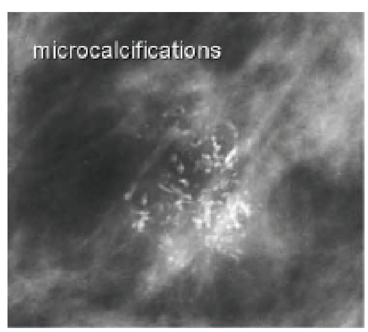

Figure 4: Microcalcifications

Mammography X-ray machine (figure 5) has similar parts of different kinds of X-ray machines as the X-ray tube, filter, detector and compression paddle. It usually has low power requirement under 40 kV. The target is used as anode material in the X-ray tube is Molybdenum and Rhodium in a machine that uses screen-film transducers. However, because of the development of digital detector, Wolfram is the optimum choice. The advantages of Wolfram is increasing lamp efficiency, improving thermal damage caused by the problem of high heat resistance. X-ray tube typically separates with a detector as 65 cm. To achieve the effect, the angle of anode must be at least 24^o for 24 x 30 cm field of view. Tube port and tube filter also play an important role in shaping the X-ray energy spectrum in mammography. They are made from Beryllium. The number of aluminum atoms (Z = 4) of Beryllium and thinness of the window (0.5 - 1 mm) to allow radiation energy transmitted efficiently. In addition, Mo and Rh anode target create characteristic radiation peaks K_α, K_β 17.5 keV and 19.6 keV (Mo) and 20.2 keV and 22.7 keV (Rh) while Wolfram target generates radiation characteristic L 8 keV to 10 keV. X-ray energy spectrum of mammography includes bremsstrahlung and characteristic radiation. For example, Mo anode tube operates at 30 kV power will generate bremsstrahlung radiation as well as features and 19.6 keV and 17.5 keV photon energy. Beryllium tube port removes the highest energy reducing image contrast and the lowest energy growing dose that not to contribute to the creation of X-ray image. The perfect energy spectrum is from 15 keV to 25 keV depends on the composition and thickness of the breast. Tube filter improves the spectral energy distribution of output by selectively removing the lowest X-ray energy beam and the highest X-ray energy to transfer most desire X-ray. With a Mo target, the filter is commonly used is Mo filter 0.03 mm or Rh filter 0.025 mm. With Rh target, filters are used as Rh filter 0.025 mm. For Wolfram target, filters include Rh 0.05 mm, 0.05 mm Ag and 0.7 mm Al. Besides, compressor parts also play a role in the examination of mammography, including screen-film transducer or digital detector. This department aims to reduce duplication of anatomical details, tissue thickness reduction and the movement of a breast. The compressor is a compressed plate that has size corresponding to the size of image acquisition unit (18 x 24 cm or 24 x 30 cm). Different compression corresponds to different X-ray tube energy input.

Tomosynthesis imaging

Basically, Tomosynthesis equipment is not much different than mammography equipment. This equipment holds the rotating part so only X-ray tube and detector turn. This method reduces the total dose of radiation in a range of shooting and shooting angles around the breast limits.

The breast tissue (glandular) is a network of carcinogen, so the index is used as the average breast-dose (average dose glandular). Because breast tissue receives various X-ray dose depending on the depth of tissue under the skin so the index is used to calculate the dose needed to photograph optimal image. The formula for calculating the dose for tomosynthesis scan is [8]:

$$D_g N_{TOMO} = D_g M_{MAMMO} \left(\frac{\sum_{\sigma=\sigma_{min}}^{\sigma_{max}} RGD(\alpha)}{N_\alpha} \right)$$

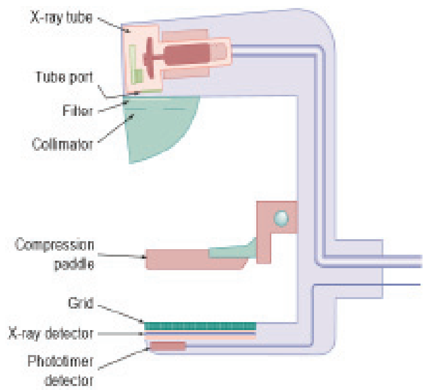

Figure 5: Mammography machine.

	DIGITAL, Mo TARGET, CELLULAR GRID			DIGITAL, W TARGET, CELLULAR GRID			DIGITAL TOMOSYNTHESIS, W TARGET, NO GRID		
THICKNESS (cm)	FILTER	kV	mAs	FILTER	kV	mAs	FILTER	kV	mAs
<3	Mo 30 μm	24	35	Rh 50 μm	25	40	Al 700 μm	26	35
3-5	Mo 30 μm	27	75	Rh 50 μm	28	80	Al 700 μm	29	50
5-7	Mo 30 μm	31	100	Rh 50 μm	31	150	Al 700 μm	33	65
>7	Rh 25 μm	33	150	Ag 50 μm	32	200	Al 700 μm	38	85

Table 1: Parameters between thickness and energy [7].

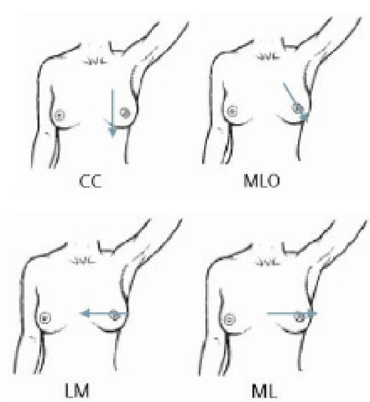

Figure 6: The directions of mammography: Cranio-caudal (CC), Medio-lateral obique (MLO), Latero medial (LM) v Medio-lateral (ML).

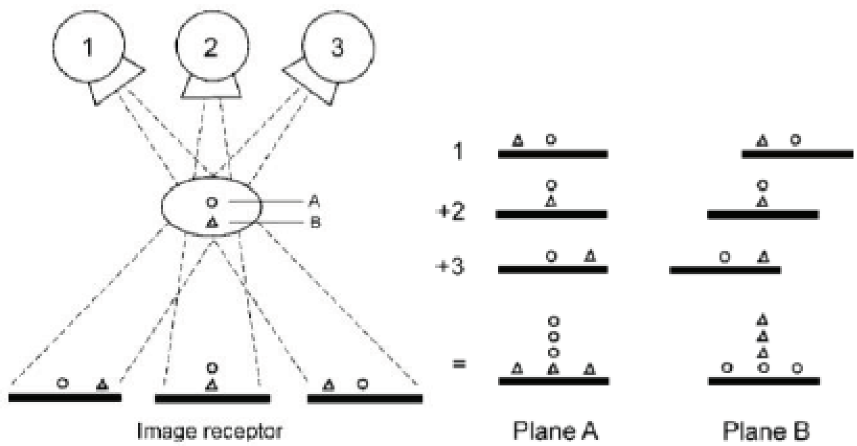

Figure 7: Tomosynthesis imaging technique [8].

with

$$RGD(\alpha) = \frac{D_g N(\alpha)}{D_g N(0^o)}$$

$D_g M_{TOMO}$ is the average dose of tomosynthesis; $D_g N_{MAMMO}$ is the average dose of mammography; $D_g N(\alpha)$ is the dose corresponding to corner (a), $D_g N(0)$ is the corresponding doses of 0 and corner N_α is the total number of shooting angle.

Because of the different shooting angles, this method enhances the efficiency in detecting tumors than conventional methods fail to detect. Figure 8 shows tomosynthesis image is clearer than mammography image.

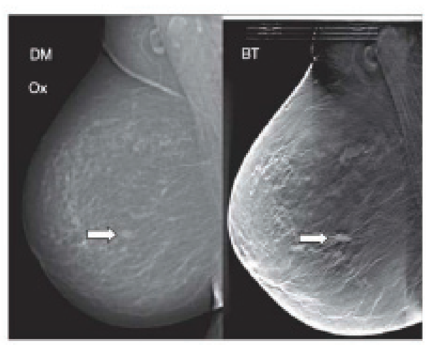

Figure 8: Digital Mammography (DM) image and Breast Tomosynthesis (BT) image [9].

PENELOPE and PENEASY

PENELOPE (PENetration and Energy LOss of Positrons and Electrons) is the simulating program based on Monte Carlo method that is programmed by FORTRAN code. It simulates the transmission of photons, electrons, and positrons in a material system artrarely defined by the user that is limited the quadric surfaces. It delivers energy from 50 eV to1GeV (figure 9).

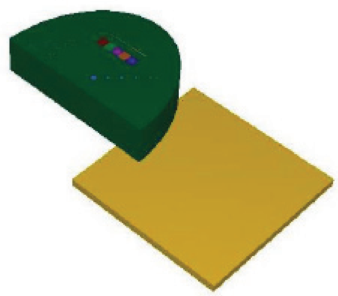

Figure 9: Quadric surfaces model.

PENEASY is a program with a common purpose with PENELOPE that uses compatible with PENELOPE. The program supports user to create X-ray image with a combination of quadric geometry and voxel geometry (figure 10).

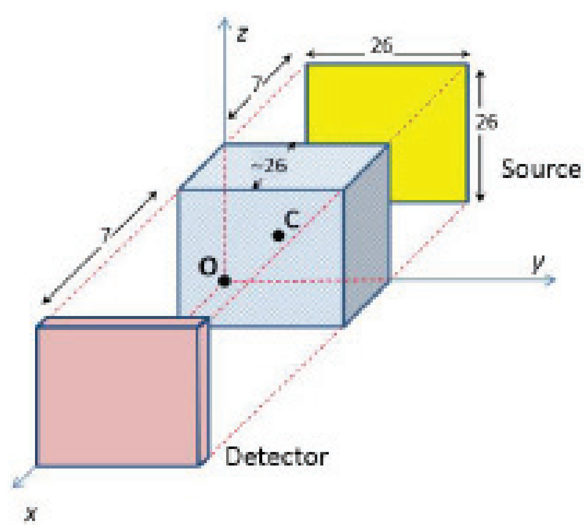

Figure 10: PENEASY model.

In this report, quadric surface geometry is configured from a mammography phantom. A phantom is a tool for checking the relevant parameters and evaluating image quality. Phantom parameters should be sensitive to change in X-ray imaging techniques. A perfect phantom will have the following characteristics:

- Features of tissue structures are almost realistic.
- Have equivalent actual size.
- Simulate the signs of breast cancer radiation.
- Easy to use.

Phantom is used as CIRS 010 (Computerized Imaging Reference Systems). Phantom model is designed with different sizes [10]:

Model	Type
010A	Thickness 5cm, 30% glandular
010B	Thickness 4cm, 50% glandular
010C	Thickness 6cm, 20% glandular
010D	Thickness 5cm, 50% glandular

Table 2: Phantom CIRS

Figure 11: CIRS mammography phantom.

PENELOPE and PENEASY create mammography image that is performed due to data from a tomosynthesis equipment [11] with 30 keV energy level. It can be seen that some details are shown such as glandular 100%, 70%, 50%, 30% and 100% adipose. The circles ($CaCO_3$) with different sizes are also shown in figure 13.

Tomosynthesis is effective in detecting mammography details that are undetectable. In figure 14a, if it is taken from CC direction, circle and square will overlap. Figure 14b and 14c form two angles taken at 65^o and 115^o, this method helps to isolate two details for diagnosis easier.

From figure 15a, it is clear that image from 70-110^0(step 2^0) gives smoother image than other images. The image would be better to increase the angles and steps taken.

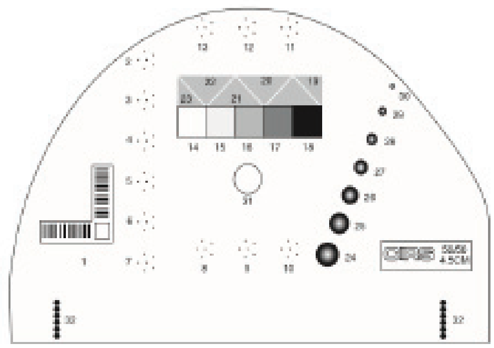

Figure 12: Structures of phantom.

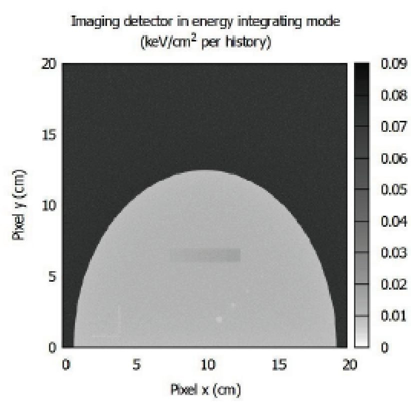

Figure 13: Phantom CIRS by PENEASY.

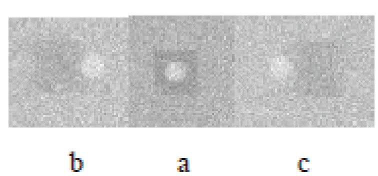

Figure 14: a. Mammography image from CC direction, b. Tomosynthesis image at 65^o, c. Tomosynthesis image at 115^o.

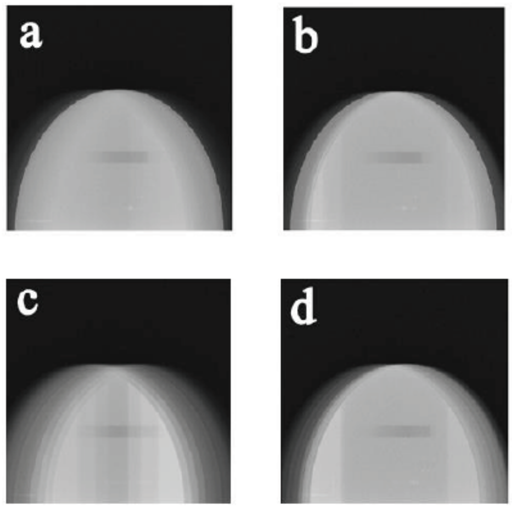

Figure 15: Tomosyntheis image: a. 70-110o (step 2^0), b. 80-100^0(step 2^0), c. 70-110^0(step 4^0), d. 80-100^0(step 4^0).

Conclusion

Breast cancer is a common disease among women and high risk of death if not detected early. Therefore, the development of high technology for the early detection and treatment is extremely important. The calculation device design is a complex task requiring detailed calculations and complete. PENELOPE program and PENEASY be used to assist in equipment design fundamentally. However, normally the simulation results are for reference only certain, should be compared with the results of other methods as well as the practical measurement results because of the method of simulation and in practice there are many different conditions and bias.

References

[1] "International Agency for Research on Cancer, Globocan 2012": Section of Cancer Surveillance.

[2] Phuong Dung (Yun) Trieu, Claudia Mello-Thoms, Patrick C.Brennan, *Female breast cancer in Vietnam: A comparison across Asian specific regions,* Cancer Bio. Med., **12**(2015), 238-245.

[3] Redonda G. Miller, *Breast Cancer Screening,* J. Gen. Inter. Med., **16**(3)2001, 206-207.

[4] Francesc Salvat, *The Penelope code system: Specific features and recent improvements,* Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo; Oct. 27-31, 2013, Paris, France.

[5] Josep Sempau, Andreu Badal, Lorenzo Brualla, *A Penelope-based system for the automated Monte Carlo simulation of clinacs and voxelized geometries-application to far-from-axis fields,* Medical physics, **38**(11) (2011), 5887-5895.

[6] Mark A. Helvie, *Digital Mammography Imaging: Breast Tomosynthesis and Advanced Applications,* Radiol. Clin. North America, **48**(5)(2010), 917-929.

[7] Jerrold T. Bushberg, "The essential physics of medical imaging", 3rd edition. China: Lippincott Williams & Wilkins, 2012.

[8] James T Dobbins III, Devon J Godfrey, *Digital x-ray tomosynthesis: current state of the art and clinical potential,* Physics in Medicine and Biology **48**(2003), 65-106.

[9] Andres Tingberg, Sophia Zackrisson, *Digital mammography and tomosynthesis for breast cancer diagnosis,* Expert Opin. Med. Diagn., **5**(6)(2011), 517-526.

[10] "Computerized Imaging Reference Systems", Inc, Tissue Equivalent Mammography QA Phantom: User Guide & Technical Information.

[11] Mayuresh Kulkarni, "Monte Carlo simulation of slot-scanning X-ray imaging systems, Doctoral thesis, University of Cape Town, South Africa, 2015.