A Framework to Visualize 3D Breast Tumor Using X-Ray Vision Technique in Mobile Augmented Reality

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***Abstract*—Breast cancer patients who require breast biopsy have increased over the past years and Stereotactic Biopsy uses series of images to carefully position the imaging equipment and target the area of concern. However, it has the constraint of accurate 3D Tumor visualization. An Augmented Reality (AR) Guidance Biopsy system of breast has become the method of choice for researchers, yet this AR tumor visualization has limitation to the extent of superimposing the 3D Imaging Data only. In this paper, a framework to visualize 3D breast tumor technique is being introduced to accurately visualize 3D tumor to see through the skin of US-9 Opaque breast phantom on a mobile display. This mobile AR visualization technique consists of 4 phases where it initially acquires the image from Computed Tomography (CT) or Magnetic Resonance Images (MRI) and processes the medical images into 3D slices, secondly, it will purify these 3D grayscale slices into 3D breast tumor model using 3D modeling reconstruction technique. Furthermore, in visualization processing, this virtual 3D breast tumor model is enhanced using X-Ray Visualization technique to only see through the skin of the phantom for better visualization. Finally, the composition of it is displayed on a smartphone device with an optimized accuracy of the 3D tumor visualization in a six degree of freedom (6DOF). The experiment was made to test the visualization accuracy on US-9 breast phantom which has 12 tumors in different sizes and categorized in 3 levels. Our frame shows the 3D tumor visualization accuracy, however, the accuracy comparison is pending. The two radiologists from Hospital Serdang performed successful visualization of a 3D tumor in an X-ray vision. The framework is perceived as an improved visualization experience because the AR X-ray visualization allowed direct understanding of the breast tumor beyond the visible surface towards accurate biopsy targets.**

***Index Terms*—Augmented Reality; Biopsy; Breast Cancer; Visualization.**

I. INTRODUCTION

The increasing rate of breast cancer is alarming with a very high count in most countries. In North America, approximately 3.2 million individuals are affected, which makes up to 1.5% of its population [1]. Although there are many types of cancers, breast cancer is the most commonly affected with over one million people each year [2]. According to recent statistics, roughly two hundred thousand women are diagnosed with breast cancer in the United States annually, and forty thousand died [3]. For many years breast cancer is known as one of the most common causes of mortality in women [4]. However, a very high false positive rate that occurs while the routine examination takes place makes the matter worst. For example, after ten mammography examinations the cumulative risk for false-positive mammography ranging from 21% to 49% [5]. This is partly caused by the lack of tumor visualization for doctors in the mammography results including x-ray. Advancement in visualization process affects tremendously on the life of many people.

Augmented Reality (AR) could help by enhancing the improvement of visualization process. The AR technology adds digital information to the visualization process that can enhance the perception of the user from the physical real-world. As an example, many AR applications take the input of the real world using a camera by detecting the objects of interest using image processing approach. It will then provide more information about the object by rendering a 3D model of its image. AR devices such as smartphones, monitor or a head-mounted display e.g. Google Glass [6], can be used to view this augmented version of the world.

Therefore, researchers are merging the medicine and AR technology to meet medical guidance system. Undoubtedly AR is widely used in laparoscopic surgeries [7] compared to heart [8] or breast. Nonetheless, more research is done in AR visualization, motivated by the challenges of minimally-invasive surgery and interventions, such as needle insertion, laparoscopic and endoscopic interventions [9]. Specifically, AR technique is where relevant information from preoperative images is superimposed with live images from surgery. Metaphorically, many people refer to this technology as x-ray vision, i.e., the surgeon is able to see through the skin or an organ and observes the operative site before he or she actually arrives there [10]. These technologies were introduced in the 1990s in industrial applications, such as the assembly and maintenance of aircraft and cars. Workers were supported by placing blueprints onto surfaces [11]. Since breast is a non-rigid organ that can change its shape depending on the patient’s posture, it is technically challenging to generate computer guidance for breast cancer surgery/biopsy.

In this paper, we are proposing a mobile-based AR X-Ray Vision framework for Breast Cancer that displays a 3D model from MRI data of the breast cancer on a US-9 Opaque breast phantom. Such visualization of breast cancer is crucial to assist physicians and technologists in training to become proficient and confident in performing the stereotactic biopsy. Here we have organized the sections as below: In Section II, we concisely refer to the related work. In Section III, we formulate the X-Ray visualization techniques and phantom-based MRI procedure using mobile technology and describes the interactive segmentation for 3D tumor reconstruction from MRI/CT Images.

II. Related Work

During the 1990's, many researchers started to develop prototypes of AR as a component of personalized medicine [12]. AR aids the surgeon by estimating information that has been processed by a computer system [13]. Such important information can be related spatially and temporarily to the site of the operation by using tracking technology that will continuously record the position of the patient and surgical instruments through sensors [14]. There has been a considerable amount of work on augmented reality and multimodality integration systems with 3D medical images [15]. In early research, AR with the breast cancer system was introduced with ultrasound-guided needle biopsy of the breast [16] in which ultrasonic images are superimposed onto live video images using a head-mounted display. Another application of AR for ultrasound-guided breast cyst aspiration is proposed two years later by Pisano et al. [9]. AR is also used in conservative breast cancer surgery, and it is shown to have an impressive result. Magnetic Resonance (MR) and Computed Tomography (CT) images also found to be useful or enhanced reality visualization in breast-conserving surgery by Sato et al. [16]. However, many of the applications are restricted to the basic augmented reality visualization where the depth of the tumor accuracy visualization is yet to be resolved [17].

In order to have depth visualization, we need to look into the use of AR for rendering X-ray views. An early effort to simulate X-ray visualization was performed by Bajura [15] as an attempt to see ultrasound imagery within patients. Their work has revealed numerous applications a real-time X-ray system can be used in and discussed the challenges regarding conflicting visual cues. Some researchers have conducted experiments to improve X-ray perception by using depth cues. For instance, Kalkofen [18] proposed a method to preserve context from the real world by overlaying synthetic data extracted from 3D models of occlusion on top of AR scenes. Farrell [19] implemented a system called Edge Overlay that provides depth cues by rendering edges extracted from real images on top of the virtual scene. The work also presented a visualization mode, called Tunnel Cut-out, to simulate multiple occluding layers. However, the Edge Overlay discards important information about occluding entities, such as colour, and the method lacks an adaptive classification of features to prevent overloading the view with too many edges [20].

Hence in our proposed system, we will be applying a smart visibility technique of Augmented Reality (AR) as X-Ray vision [10], where physician or radiologist would be able to see through the skin of breast phantom and observes the stereotactic breast biopsy procedure accurately aligning the breast cancer visualization.

III. The Proposed Framework

In this session, the proposed framework is explained to visualize 3D Breast Tumor using an augmented reality x-ray vision technique. The framework (Figure 1) is comprised of 4 modules: 1) Medical Image Acquisition, 2) 3D Model Reconstruction, 3) AR Visualization Technique, and 4) Displaying the final composition onto a mobile or tablet.

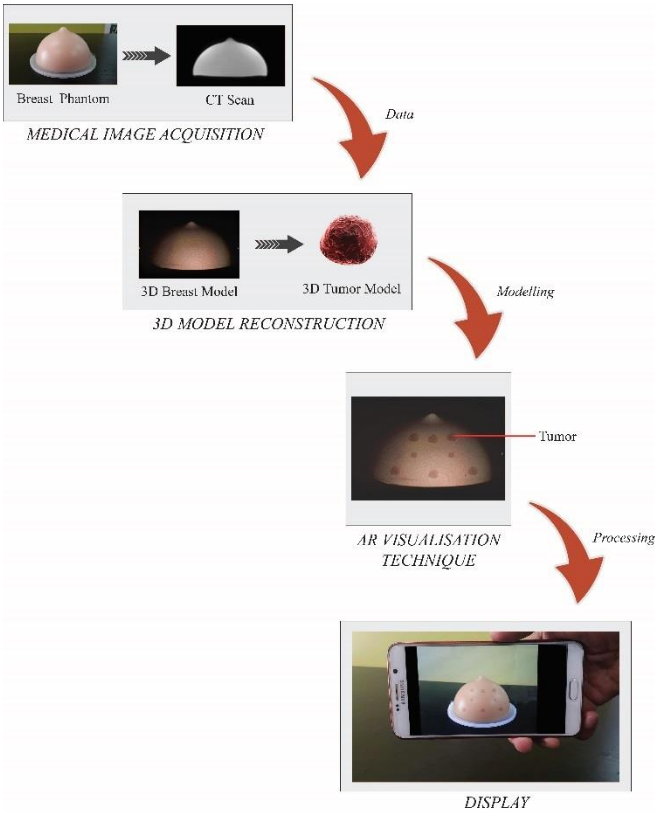

Figure 1: Proposed framework

A. *Medial Image Acquisition*

In order to obtain a 3D model of the breast, first, we have to acquire the data which has been taken using MRI on Breast Phantom US-9. Therefore we have used modern 3D imaging modalities, such as 3D Slicer where we can convert the MRI data into slices. To obtain MRI with multispectral features we need to use Constrained Energy Minimization (CEM) algorithms to process the multispectral images, so as to generate images with high background contrast, which would facilitate the subsequent contour detection. The CEM algorithm was derived from the minimum variance distortionless response (MVDR) processed by the sensor array, and it required only the target's information (no background information needed) during its entire processing. The potential of CEM was better showcased when the target and a complex background were presented in the same image. We stacked MR images from the same section on different spectrums to form a 3D cube. Then, the set of pixels at the same location on different spectral images could be regarded as a column vector. Hence, CEM used the correlation between the column vectors of each location and of the target for classification.

B. *3D Model Reconstruction*

Modeling is the process of generating a 3D model from the 2D medical MRI/CT scan images. In this paper, we propose Marching Cube algorithm to generate a 3D model of breast tumor from 2D slices.

1) *The Classical MC Algorithm*

The classical MC algorithm was presented by Lorensen [21], in which the data sets are 3D orthogonal. As for the sequential medical images, eight vertices of a voxel are selected from two neighbouring layers shown in Figure 2, in which four of which are from one neighbour layer.

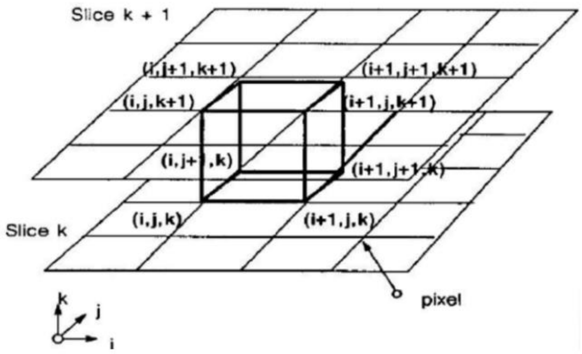

Figure 2: Creation of voxel

Since there are eight vertices in each cube and two states, inside and outside, there are only 2^8 =256 ways a surface can intersect the cube. By enumerating these 256 cases, we create a table to look up surface-edge intersections, given the labelling of cubes vertices. Triangulating the 256 cases is possible but tedious and err-prone. Because of symmetry and complementarily, there are only 15 canonical configurations as shown in Figure 3 and all of the corresponding triangulations of the isosurface can be easily listed one-to-one. So for any given configuration, Lorensen[21] provides a look-up table which gives the corresponding canonical configuration and hence its triangulation.

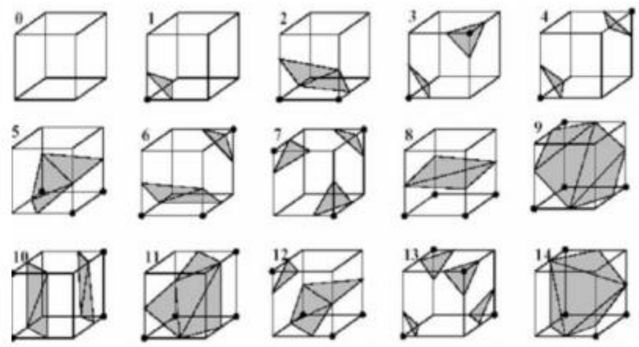

Figure 3: Triangulated cubes

We created an index for each case, based on the state of the vertex. Using the vertex numbering in Figure 4, the eight-bit index contains one bit for each vertex. This index serves as a pointer into an edge table that gives all edge intersections for given cube configuration.

Using the index to tell which edge the surface intersects, we can interpolate the surface intersection along the edge.

C. *AR Visualization Technique*

Visualization is nothing but the process which defines some parameters for the rendering of the object. AR X-ray can represent an occluded region in-situ with the user's current view, improving cognition by representing both as a single, unified visual event instead of disparate events. This is recognized as requiring greater cognitive effort [22]. Naively rendering AR Xray, such as rendering the occluded region on top of the occluder can be problematic. Bajura et al. [23] first observed the issues that occur when rendering occluded regions, noting that "the [occluded] images did not appear to be inside the subject, so much as pasted on top of her". Furthermore, such a rendering simply swaps the roles of the occluder and occluded scene, losing any perceptive contribution the occluder makes to the overall scene [24]. This is primarily an issue of depth perception, and several works have attempted to address this by rendering portions of the occluder over the occluded region. While it may seem counter-intuitive, occlusion is the most important depth-cue, it is very difficult to have incorrect occlusions and a perceptually coherent scene.

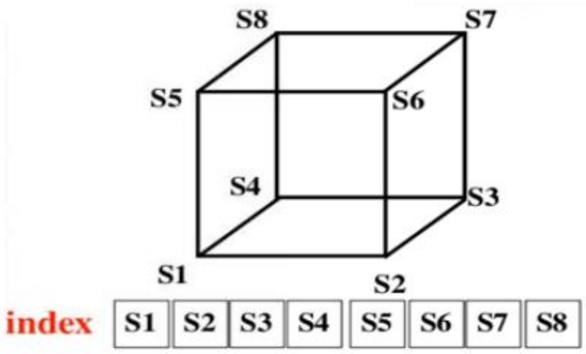

Figure 4: Triangulated cubes

Our approach aims at preserving correct occlusions as much as possible. The X-ray visualization in this work is composed of six steps: (i) Edge Detection, (ii) Perspective Estimation, (iii) Silhouette Computation, (iv) Brightness Adjustment, (v) Virtual Scene Definition, and (vi) Final Image Composition. Some of these steps are independent and thus can be executed concurrently. Some image processing operations were replaced by an equivalent, yet faster approaches, in order to achieve real-time performance on mobile devices. For instance, bitwise operations between images and masks were used instead of blending. Moreover, methods that demand high processing operations, like edge detection, perspective estimation, and silhouette computation, were performed on images with reduced resolution. In this case, images were resized to a lower resolution right after the scene capturing and restored to their original size during the image composition step.

D. *Mobile Display*

Mobile displays are a good alternative to HMD and HMPD systems for AR applications, particularly because they are minimally intrusive, socially acceptable, readily available and highly mobile. Currently, there are several types of Mobile devices which can be used for a mobile AR platform: Tablet PCs, and smartphones. Most of the relatively early wearable prototypes, like "Touring Machine" [25], were based on tablet PCs, notebooks or custom PC hardware, and usually had hardware in a large and heavy backpack. They provided greater computational power and input options, however, the current era smartphones are very powerful and can run a supported 3D tracking of passive paper markers and correct integration of 2D/3D graphics into the live video-stream at interactive rates with high video stream resolution, great graphics and memory capabilities. Hence the final composition of the display is going to be visualized on the mobile or tablet where it's easier for the physicians and radiologists to have the view in 6 DOF (degree of freedom).

IV. METHODOLOGY

The framework was implemented on Samsung Note 5 mobile phone and using an android version 5. We used CT scan for image acquisition, which is suitable for capturing subtle intensity variation of a breast tumor with high resolution. In Figure 5, is an architectural overview of the proposed framework.

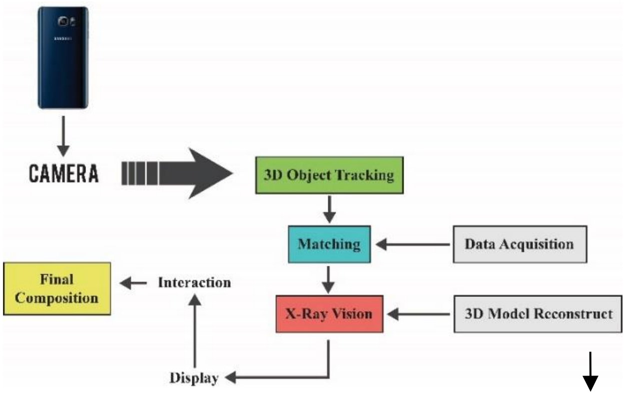

Figure 5: An architectural overview of the proposed framework

A. *Object Tracking*

We are using an open source vuforia tool to use their Object Tracking which allowed us to detect and track intricate 3D Breast objects. Hence this vuforia object tracking can be used to build rich and interactive experiences with 3D objects. In our experience, it is augmenting a breast phantom with 3D breast tumor.

B. *Matching*

It is a very lengthy process due to the data acquisition because the matching process is purely based on data and in our case, it is a Breast Phantom data from CT scan. Therefore, to match such object tracking, we surely required the 3D data acquisition with position over calibration.

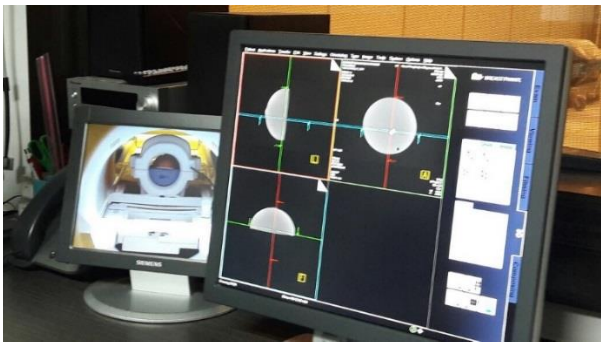

Figure 6: Data Acquisition from CT using US-9 Opaque Phantom

After receiving the slices from the DICOM viewer we have to further do the 3D segmentation in order to reconstruct 3D Breast tumor model. Here we are using an open source tool Horos and made the integration with the mobile so that it can automatically produce multiple 3D models. In our case figure 7, shows the 3D tumor model and 3d Breast model. However this integration wasn't successful due to the integration error, therefore a 3D(tumor and breast) segmentation been made manually under the supervision of two radiologist in Hospital Serdang.

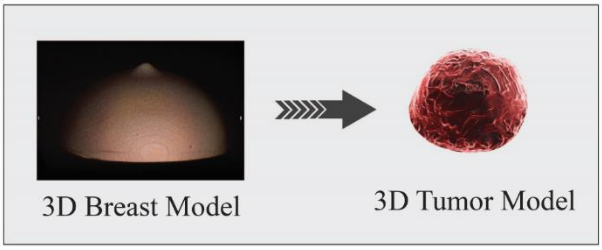

Figure 7: Successful 3D reconstruction of Breast Tumor Model

C. *X-ray Vision*

X-ray Vision is a technique so that we can see the tumor inside the phantom for eliminating the manual process of stereotactic biopsy, therefore to have a better visualization is required. X-Ray vision is based on multiple steps Figure 8.

V. RESULT & DISCUSSION

We have performed an experiment comparing our implemented frame with stereotactic biopsy procedure for the task of targeting needle biopsies upon accurate tumor visualization in training phantom. Our hypothesis was that our method would be comparable in terms of needle placement accuracy for this task. The experimental component of this study was performed using Mobile AR system described above. The application works smoothly on this phone with the best resolution of 800x600 pixels, however, it is not smooth if it is less than 8 frames per second in a higher resolution.

The proposed system is a new tool to help breast tumor visualization. While we were doing an experiment with the radiologist, they share the opinion that this visualization has several potentials for biopsy procedure however if there is a depth measurement so that it will help them to know how deep is the tumor located.

There is a limitation to our methodology, which is on the AR 3D Object tracking as it was disturbing the accuracy of tumor visualization. Secondly, an extensive research needs to be done to find the accuracy measurement between our framework and ultrasound as both are real-time.

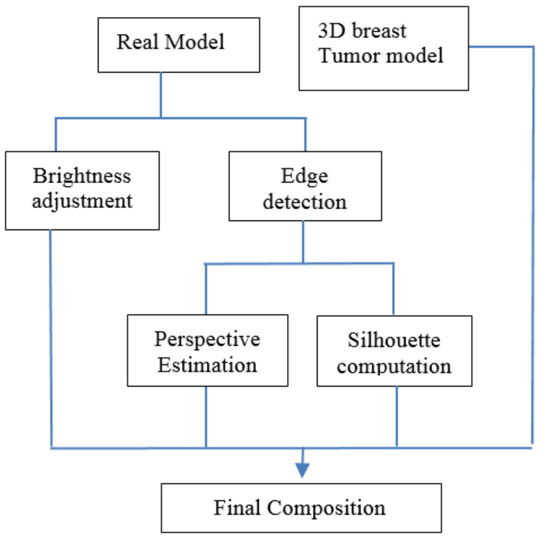

Figure 8. Process flow of X-Ray vision

VI. CONCLUSION

In this paper, we explained the implemented proposed framework to visualize 3d Breast tumor using x-ray vision technique on a handheld device to see through the breast phantom of 3D Tumor over the live video stream. Based on the framework, the processes performed accurate and smooth visualization on US-9 breast phantom in the laboratory as well as multi-tumor visualization was accurate from MRI/ CT data. The augmented reality six degree of freedom display was found to be an intuitive way to relate the breast tumor stereotactic biopsy procedure, however, was not so effective due to the 3d object tracking error. The volumetric tumor seen below the semitransparent visible opaque phantom surface allowed visualization directly towards a biopsy target. The way of visualization was thought to be more comprehensive compared to traditional AR visualization where physicians or technologists is able to see 3D breast tumor through the skin and it gives a clear understanding of how to perform the stereotactic breast biopsy in their training procedure. It may also be useful for surgery or diagnostic. However, more research needs to be done on the accuracy and tracking whether visualization accuracy is enough or accuracy is directly dependent on tracking types.

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