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Stationary digital breast tomosynthesis for breast cancer detection

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A stationary tomosynthesis mammography system with a carbon nanotube-based x-ray source array can shorten imaging time and improve image quality.

Mammography is currently the most effective screening and diagnostic tool for early breast cancer detection. In fact, the recent reduction in the breast cancer mortality rate has been attributed to increased mammographic screening[1]. However, mammography suffers from several limitations. It is very difficult to distinguish cancer from overlying breast tissues on two-dimensional mammograms, and radiologists' interpretation of the images may vary. There are also higher rates of false-positive and false-negative test results because dense tissues interfere with the identification of abnormalities associated with tumors. To solve this problem, researchers in the late 1990s developed a novel technique called x-ray digital breast tomosynthesis (DBT).

DBT is a three-dimensional imaging technique that uses a series of projection images acquired at different angles to provide reconstruction planes in the breast. Several commercial vendors, including GE[2], Hologic[3], and Siemens[4], have manufactured prototype DBT scanners that are based on full-field digital mammography (FFDM) systems. To generate the series of projection images, a conventional x-ray tube mounted on a rotating gantry fixes the imaging beam on the breast, while the tube moves in an arc to generate images at multiple angles. A typical tomosynthesis scan can take anywhere from 20 seconds to more than 1 minute. Compared with conventional mammography, the prolonged imaging time introduces patient motion blur on the images. Moreover, gantry motion leads to a larger effective x-ray focal spot size, which degrades the image quality.

To overcome this problem, we proposed a stationary digital breast tomosynthesis system using a carbon nanotube-based field emission x-ray source array[5,6]. The device, called Argus, uses spatially distributed x-ray sources, so it acquires the projection images without source or detector movement. It reduces the total imaging time and potentially improves image quality.

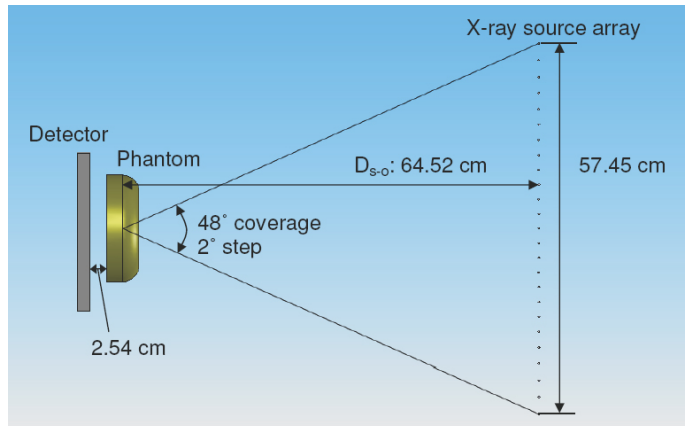

Figure 1. *Schematic of the Argus geometry. D_{s-o}: source-to-object distance.*

We have designed and constructed a prototype system composed of a 25-pixel x-ray source array, a flat panel detector for full-field mammography, a control unit for x-ray sources, and a computer work station. As shown in Figure 1, the geometry of the Argus system, including source-to-object distance, angle coverage, and view number, is comparable to that of conventional mammography and DBT systems. Table 1 shows a comparison between Argus and other prototype systems. Our target goal is the acquisition of 25 projection images in 11 seconds at 0.2mm resolution. By contrast, the Siemens system at the same dose requires 20 seconds to take 25 images with ∼0.3mm focal spot size—and additional blur due to gantry motion ranges from 0.2mm to 1mm depending on the rotation speed.

The key component of the Argus system is the 25-pixel x-ray source array. Other medical applications like micro-CT[7] have

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Table 1. *The design specifications of the prototype stationary DBT scanner Argus are compared with those of three commercial prototype scanners.*

	UNC: Argus	GE: Senographe 2000D	Siemens: Mammomat Novation	Hologic: Selenia
X-ray kVp, mA	∼28kVp, 10mA	25-30kVp, ∼130mA	∼28kVp, ∼180mA	24-39kVp, ∼100mA
Focal spot size	0.2mm	0.3mm + blur due to gantry motion	0.3mm + blur due to gantry motion	0.3mm + blur due to gantry motion
Gantry motion	Stationary	Step and shoot	Continuous	Continuous
View numbers	25	11	25/49	11
Imaging time	11.2s	7s	20s/39.2s	18s

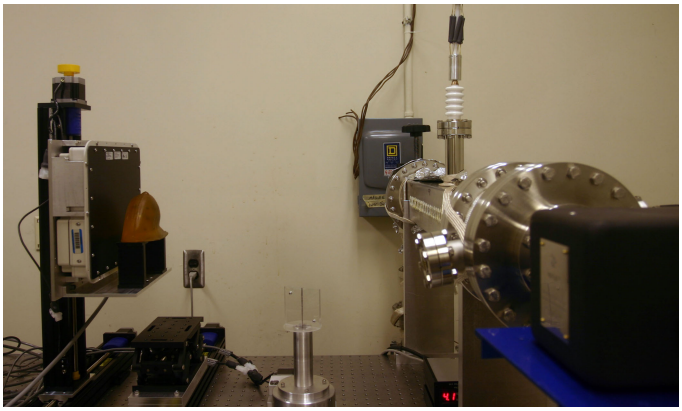

Figure 2. *The assembled Argus system.*

employed a field emission x-ray source based on carbon nanotubes; we use it here because it can be easily miniaturized. The 25 identical x-ray sources each consist of one carbon nanotube-based cathode, one gate electrode, two focusing electrodes, and one anode. Unlike thermionic x-ray sources, the field emission x-ray source is switched instantaneously by the low gate voltage (with less than 1μs accuracy). The focusing electrode voltages control focal spot size.

The system has been fully assembled (Figure 2) and is currently under testing. A customized control unit synchronizes the x-ray source and detector. Imaging software for imaging acquisition and post processing has already been developed, and we also have a set of previously developed calibration procedures. To reconstruct the slice images, Argus uses an iterative method based on the ordered subset convex algorithm. Our next steps include phantom imaging and reconstruction testing, as well as a comparison imaging test between Argus and other prototype systems.

In the future, x-ray sources with 50mA peak current may further reduce total imaging time to 3 seconds. The novel stationary design may be incorporated into other advanced imaging techniques, such as dual energy imaging and quasi-monochromatic imaging. The Argus system may also inspire new approaches for medical devices requiring x-ray sources at spatially distributed locations.

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