Optimization of Carbon Nanotube based CBCT for Improved Imaging of Soft Tissue and Metal Artefacts

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Abstract

Dental imaging techniques have significantly evolved over the last four decades. Although traditional computed tomography generates improved contrast compared to standard bitewing radiography, the rise of cone-beam computed tomography (CBCT) allows for a compact medical imaging device, widely used in clinics due to its isotropic images and diagnostic accuracy. Carbon nanotubes (CNT) are an evolving technology which allow for compact x-ray source arrays. This research aims to analyze and optimize the collimation, reconstruction software, and geometry of a prototype bench-top CBCT device using a carbon nanotube based x-ray source.

Background

Typical X-ray tubes generate electromagnetic radiation through thermionic emission includes:

- high temperatures
- slow temporal response
- substantial physical size

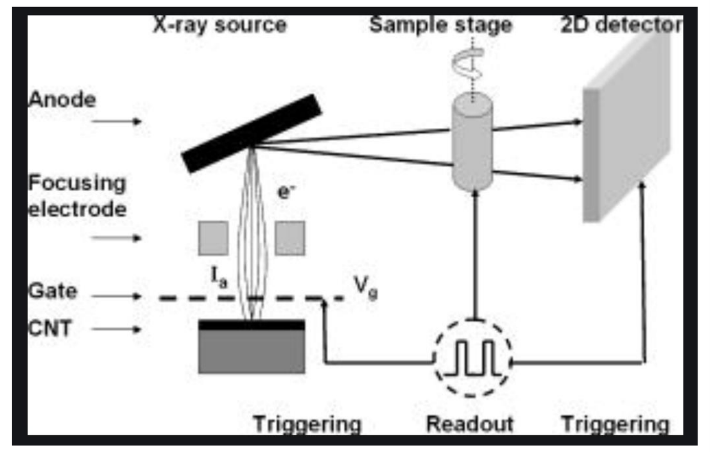

Figure 1. Diagram of CNT X-ray Source [14]

In contrast, carbon nanotubes (CNT) (Fig. 2) are composed cylindrical molecules, which include single-layer carbon atoms [5]. The molecular interactions between carbon nanotubes provide:

- high strength
- low weight materials
- high conductive electrical properties

Through field emission, CNT cathodes produce electrons at room temperature with only a moderate voltage [2]. CNT sources can be constructed into multi-beam X-ray source arrays which can image an object without mechanical motion [50].

Cone beam computed tomography is a technique in dental imaging today for its ability to produce isotropic images with strong contrast. Current challenges of CBCT include:

- Scatter
- greater radiation dose

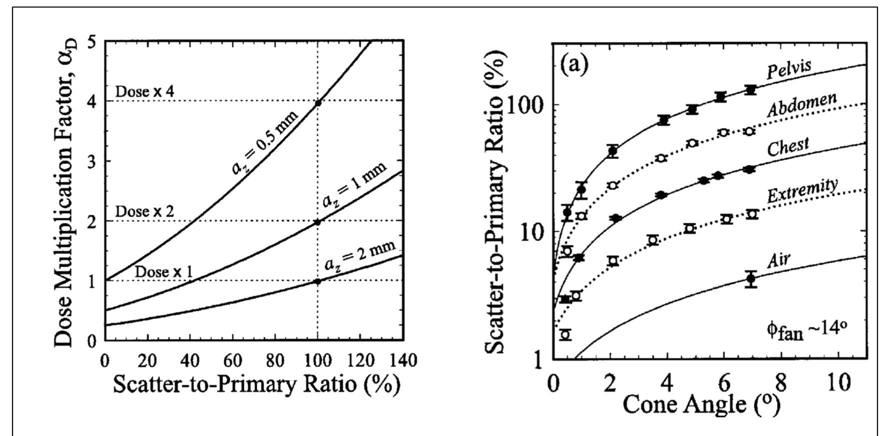

Figure 2. Plots from CBCT Literature review [7]

By decreasing the size of the cone beam, the amount of scatter photons is reduced, producing an image with improved contrast (Fig. 2) [7]. Decreasing the scatter (Fig. 2, Left) will cause a lower dose multiplication factor, therefore reducing the radiation needed to achieve the same CNR as a scatter free case [7]. With a single CNT X-ray source we can simulate the multi-beam X-ray source by movements along a vertical stage.

Material and Methods / Results

Reconstruction Software

Reconstruction is the process of the taking the detector counts measured during imaging phase and reconstructing the image from data numerical data. There are two forms of reconstruction algorithms, 2D and 3D reconstruction. During the imaging process, an X-ray image is taken of the patient's jaws using multiple x-rays sources. Each source covers a different region of detector. These images must be stitched together by computer algorithms in order to have any meaningful X-ray images. For this project, we employed tested 2D parallel geometry algorithms found in the ASTRA toolbox. We modeled out current CBCT geometry in the MATLAB and entered the necessary parameters, source position, detector position etc, for the algorithm.

Collimation Design

Experimental results were produced using :

- a source-to-object distance of 300 mm
- a source-to-imager distance of 500 mm
- an object radius of 100 mm

These parameters found a total of 10 focal spots spaced 10 mm apart to be ideal for collimation.

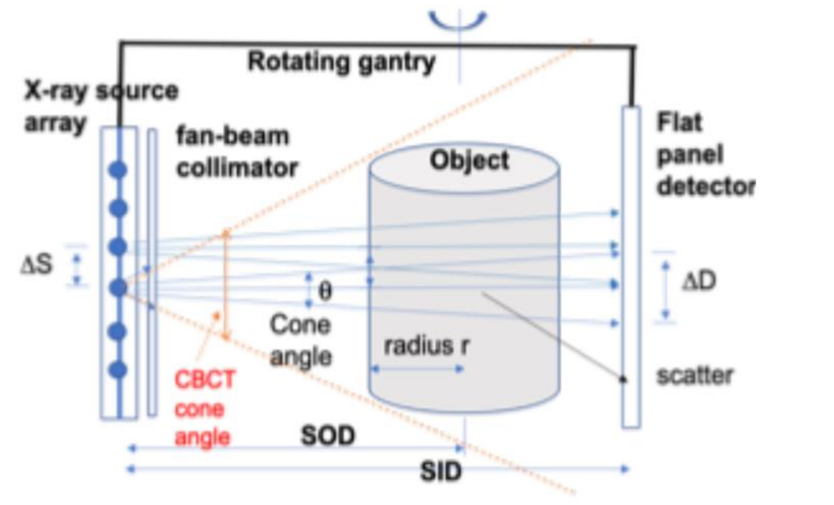

Figure 3. Schematic of bench-top CBCT device

This produced a cone angle of approximately 2.86 degrees (Fig. 3). Setting an air gap of 50 mm to account for crosstalk between the square 1 mm focal spots, square collimator slit openings with a length of 3.5 mm, and a total collimator thickness of 20 mm were found to agree with system specifications and similarly optimized CT systems [11].

System Geometry

Based on this analysis, system geometry should include:

- translation stage 134 mm from the base plate
- resting plate 77 mm from base plate

The active region on the detector should be located 37.5 mm from the bottom of the detector holder. Raising the detector to a height that allows the lower collimated rays to hit the screen at 119 mm from the plate will allow for optimum scanning. This would require a plate holding the detector to be 81.5 mm tall.

Figure 4. LEFT: CBCT phantom reconstruction of yz axis, with region of interest of 8 cm x 13 cm, RIGHT: CBCT phantom reconstruction of xy axis]

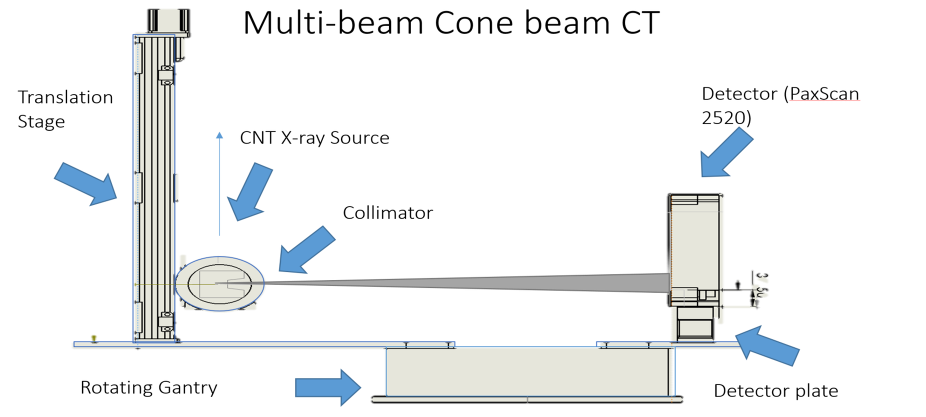

Figure 5. Schematic of bench-top CBCT device

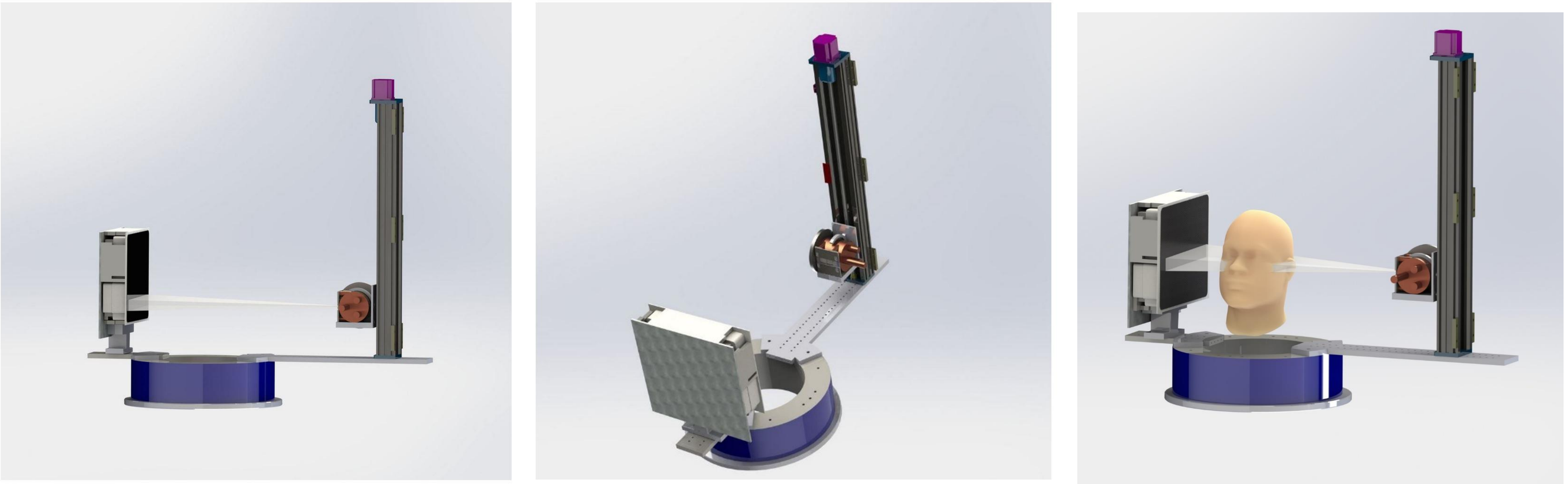

Figure 6: Solidworks 14 final rendering of bench-top cone-beam CT system

Discussion and Conclusions

Due to a wide cone angle and the large coverage required for each scan, CBCT suffers from both scattering and a larger radiation dose than radiography. The creation of a CNT multi-beam CBCT device would allow for several projections, with smaller cone angles, to be collected by a flat-panel detector. This would decrease the cupping scatter caused from larger cone angles. By improving the scatter, this CBCT device could reduce the presence of metal artefacts present due to crowns or orthodontic appliances, which hinders other CBCT devices. Also, CBCT is less reliable for detecting conditions, like oral cancer, which occur in soft tissue. A deduction in scatter could improve the contrast and increase CBCT's use as a diagnostic tool. The use of multiple smaller fan beams through a region could also allow for less overall exposure to the patient.

As a result of Covid-19 restrictions, the measurements used within this study were deduced from images taken of the current CBCT machine and are prone to uncertainly. During the next steps for creating this device, careful on-site measurements should allow for greater confidence in the vertical position of the detector. Later papers will further characterize this prototype design and determine the feasibility of multi-beam CNT X-ray source.

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