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Adaptive CT for High-Resolution, Controlled-Dose, Region-of-Interest Imaging

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Abstract

We have developed a flexible x-ray micro-CT system, named FaCT, capable of changing its geometric configuration and acquisition protocol in order to best suit an object being imaged for a particular diagnostic task. High-performance computing technologies have been a major enabling factor for this adaptive CT system in terms of system control, fast reconstruction, and data analysis. In this work, we demonstrate an adaptive procedure in which a quick, sparse-projection pre-scan is performed, the data are reconstructed, and a region of interest is identified. Next, a diagnostic-quality scan is performed where, given the region of interest, the control computer calculates an illumination window for on-line control of an x-ray source masking aperture to transmit radiation only through the region of interest throughout the scan trajectory. Finally, the diagnostic scan data are reconstructed, with the region of interest being clearly resolved. We use a combination of a multi-core CPU and a pair of NVIDIA Tesla GPUs to perform these tasks.

I. Introduction

In routine medical imaging procedures, computing power becomes a central concern only after the data have been acquired for such tasks as reconstruction, image processing, segmentation, etc. In an adaptive imaging procedure [1] [2] [3], where prior information and preliminary scan data can be used to inform and direct the diagnostic scan, computing power becomes of concern earlier in the imaging chain. In this case, computing resources might be directed towards analysis of the preliminary scan data, determining the adaptation strategy, and system control, with the end goal of improving diagnostic accuracy.

For imaging tasks in transmission imaging, we are concerned not only with improving the diagnostic accuracy of the scan, but also with minimizing the radiation dose used to arrive at an accurate diagnosis. In this paper, we consider the situation where we would like to take a readily identifiable object, such as a tumor under treatment, and investigate it more closely, perhaps to determine the efficacy of the treatment, while keeping radiation dose low. In the following, we describe an adaptive imaging procedure for accomplishing this task and highlight the role of modern computing hardware in the adaptive procedure.

II. CT System and Capabilities

Design details of our custom-built micro-CT system, dubbed FaCT (see Figure 1), have previously been published in [4]. By way of review for features relevant to this paper, FaCT can change its magnification on the fly by moving its source and detector - which are set at a fixed separation - relative to the object. The available magnification range depends on the size of the object. Additionally, FaCT possesses a beam-masking aperture that uses four independently controllable tungsten blades to shape the emitted x-ray cone beam in rectangular patterns not necessarily symmetric about the central ray. The aperture is shown in Figure 2.

FaCT relies upon two computers. An onboard control computer mounted on the rotating gantry directs all configuration changes as well as the image acquisition. FaCT takes human input from a workstation computer that houses two NVIDIA Tesla GPUs for fast reconstruction and other computational tasks requiring high data throughput. The two computers are linked via both standard wireless Ethernet, and wired gigabit Ethernet over a slip ring and stay in constant communication.

III. Adaptive Procedure

Our adaptive procedure consists of two separate scans: a quick, low-dose, sparse-projection preliminary scan to obtain some data on the object, and a diagnostic scan which uses the preliminary scan data to inform its acquisition geometry and procedure to improve task performance. In general, we allow for a mathematical observer, a human observer, or a combination of both to be used to perform the task.

The preliminary scan data are quickly reconstructed on the workstation GPUs and presented to a human observer who determines a region of interest (ROI) in 3-D space by drawing the ROI within the reconstruction using a computer mouse.

Given this ROI and the preliminary scan data, the onboard computer sets the system to the maximum possible magnification for the object. Furthermore, it calculates an illumination window about the region of interest and directs the masking aperture to adjust its blades to illuminate the ROI for all projections in the diagnostic scans acquisition trajectory. In this way, we obtain high-resolution data of the region-of-interest, while delivering radiation dose only where it is needed.

While the diagnostic scan is running, we use fast forward projection on the GPUs to predict the data missing in the diagnostic scan due to masking the x-ray beam. To do this, we use the reconstructed preliminary scan data as an estimate of our object and form a predicted projection for each actual projection to be acquired during the diagnostic scan. In this way, we avoid the problem of truncated data and can reconstruct the chosen ROI at high resolution. Reconstruction of the diagnostic scan is also performed on the GPUs.

IV. Results

In order to demonstrate the adaptive procedure described above, we fabricated a special phantom for the task. A dimensioned schematic and photo of the phantom are shown in Figure 3. The phantom consists of a hollow tube with an off-axis resolution phantom inserted into the side of the tube. The phantom is intended to demonstrate the procedure's ability to resolve a small region of interest within the volume of some object.

Our preliminary scan consists of 20 projection images taken at equally spaced points along a circular acquisition trajectory. The preliminary projections were taken at a magnification setting of 1.6X. An example projection from the preliminary scan is shown in Figure 4(a).

Once the preliminary scan data are acquired, they are reconstructed on the GPUs and presented to the human operator who selects a region of interest within the 3-D reconstruction volume using a computer mouse. A screen shot of this interface is shown in Figure 5. The object shown in the display panels is the reconstruction of the preliminary scan data.

The diagnostic scan was performed with 180 projections around a circular acquisition trajectory at a magnification setting of 2.7X. An example projection of this masked set of projections is shown in Figure 4(b).

Using the truncated diagnostic scan data, filled in with the data predicted from the scout scan, we reconstruct the region of interest clearly, as shown in Figure 6.

V. Conclusion and Discussion

We have demonstrated that, by using an adaptive imaging procedure, we can successfully reconstruct and investigate only a region of interest, while concurrently controlling and generally reducing the radiation dose used to accomplish the task. To perform this adaptive imaging procedure in a tractable amount of time, we required heavy use of high-performance computing platforms, in this case, a pair of graphics processing units.

In future work, we intend to quantify the radiation dose reduction achieved. Additionally, we plan to extend this procedure to a helical acquisition trajectory in order to accommodate axially longer regions of interest.

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Fig. 1.
The FaCT adaptive x-ray micro-CT system shown with front cover removed.

Fig. 2. Beam-masking aperture shown attached to the x-ray source. The aperture uses four independently controlled tungsten blades to mask the emitted x-ray beam.

Fig. 3. "Region-of-interest phantom" used to demonstrate this adaptive scan. (a) Schematic of phantom with dimensions shown in millimeters. Hole spacings are equal to twice their respective diameters; (b) Photo of phantom

Fig. 4. Example projections from the preliminary scan and the diagnostic scan. In both cases, black corresponds to values of complete attenuation. (a) A projection from the preliminary scan after detector-specific corrections have been performed. (b) A raw projection from the diagnostic scan where the magnification has been increased and the x-ray beam has been masked by the beam-masking aperture to only illuminate the region of interest.

Fig. 5.

Screenshot of interface for selecting a region of interest from the reconstructed preliminary scan data. The selected region of interest is shown as a light green box in each of the views.

Fig. 6.
A trans-axial slice of the reconstruction from the diagnostic scan data. The region of interest selected in Figure 5 is clearly resolved.