Ingenuity Data Acquisition and Sampling

Ingenuity Data Acquisition and Sampling (Ingenuity DAS) is a new technique that provides an alternative to dynamic z-focal spot (ZFS) imaging, which reduces helical MDCT imaging artifacts and provides improved resolution. This paper introduces Ingenuity DAS and demonstrates how it provides high-resolution, 128-slice, thin reconstructions that are clinically equivalent to those resulting from ZFS standard resolution acquisitions, that exceed those resulting from ZFS high-resolution and ultrahigh- resolution acquisitions, and that exceed the quality exhibited by other "slice-doubling" approaches.

Introduction

The introduction and rapid evolution of multidetector computed tomography (MDCT) have enabled many clinically relevant advances in medical imaging. These advances include the ability to image the coronary arteries and cardiac anatomy with increasing precision across a wider patient population, to facilitate more rapid trauma, pediatric and vascular exams, and to enable dynamic perfusion imaging of organs such as the brain. Nonetheless, thin-slice reconstructions from helical MDCT scans may suffer from helical imaging artifacts when visualized in the axial plane.[1] These helical artifacts arise from a phenomenon known as aliasing, which results from an undersampling of data in the longitudinal (z) direction.

A number of approaches may be taken to prevent or reduce the appearance of these helical imaging artifacts. One approach is to reconstruct thicker slices that are at least twice the acquisition thickness so that the minimum sampling criteria is met; however, this results in an undesirable reduction in the z-resolution of the reconstructed images. Another approach that has been proven to be successful has been to increase the imaging sampling frequency through the use of an x-ray tube with a dynamic z-focal spot (ZFS) to improve the system sampling rate, thus doubling the number of slices; and to reduce the appearance of artifacts, thus enabling higher z-resolution reconstructions.[2] Despite their success, a potential limitation of such systems is the inability to utilize ZFS in high-resolution or ultrahigh-resolution acquisitions due to a conflict between the z-sampling and in-plane detector sampling schemes. A third, more recent, adaptive-upsampling (slice-doubling) approach attempts to dynamically smooth large gradients detected in the projection domain.[3] However, this smoothing blurs (reduces the resolution of) fine structures – the very clinical features that should be preserved – in the reconstructed thin-slice images.

This paper presents Ingenuity Data Acquisition and Sampling (Ingenuity DAS). As part of the Ingenuity CT, this technique provides high-resolution, 128-slice, thin reconstructions that are clinically equivalent to those resulting from ZFS standard resolution acquisitions, that exceed those resulting from ZFS high-resolution and ultrahigh-resolution acquisitions, and that exceeds the quality exhibited by other approaches that have been introduced to reduce helical imaging artifacts or double slices.

PHILIPS

sense and simplicity

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Prior to reconstruction with aperture-weighted wedge or more recent iterative reconstruction algorithms, raw data sampling is increased using a sophisticated, high-order interpolator to provide twice the number of rows of detector data (e.g., for a 64-channel scanner, this produces 128 slices of image data) and enable high z-resolution and reconstruction.[4,5] Volumetric total variation minimization is then applied to this more densely sampled data to reduce the potential for artifact manifestation while preserving anatomical detail and noise texture.[6] Given its implementation, Ingenuity DAS may also be used in high- and ultrahigh-resolution acquisitions that may prohibit ZFS from being utilized due to potential conflict between the longitudinal and in-plane sampling schemes. Figure 1 summarizes Ingenuity DAS.

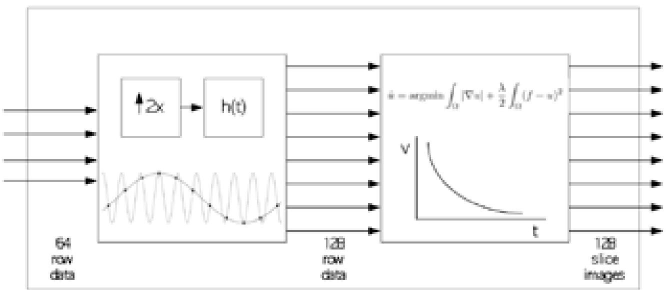

Figure 1: Ingenuity Data Acquisition and Sampling

Results

Clinical Evaluation of Ingenuity DAS

1669 helical brain and neuro computed tomography angiography (CTA) image pairs, acquired and reconstructed simultaneously with both non-Ingenuity and Ingenuity DAS, were blindly reviewed by a neuroradiologist at a leading university hospital in the United States. The neuroradiolgist's evaluation concluded that the Ingenuity images were better than the non-Ingenuity images in all cases, and that in the CTA images he observed that small vessel segments were clearer in the Ingenuity images. Figure 2 demonstrates the resulting reduction in helical imaging artifacts and the preservation of anatomical detail in high-resolution, thin-slice reconstructed data in the axial plane.

Chest and abdominal scans are subject to the same types of helical imaging artifacts noted in the head. Figure 3 shows an example of the reduction in helical imaging artifacts and preservation of anatomical detail in high-resolution, thin-slice chest images that were acquired and reconstructed simultaneously with both non-Ingenuity and Ingenuity DAS.

Preservation of Resolution

In order to test the z-resolution of Ingenuity DAS thin-slice reconstructions, measurements were made on a disc phantom. The disc phantom was 0.1 mm thick, and reconstructed images were made at a 0.2 mm increment around the disc from a helical scan. Slice-sensitivity profiles were made through the reconstructed volume. The slice-sensitivity profiles of non-Ingenuity and Ingenuity images were substantially equivalent, with effective slice thicknesses differing by only 0.001 mm.

To clinically compare the results of the techniques reviewed in the Introduction, thin-slice data from a 64-slice, non-ZFS, non-Ingenuity scanner was reconstructed. In addition, the data was reconstructed in thicker slices with the previously published adaptive upsampling approach, and also using data acquired simultaneously with 128-slice Ingenuity DAS. Comparisons between each method and the 64-slice, non-ZFS, non-Ingenuity data were made using difference images. Figure 4 demonstrates the clinical impact of the various approaches. Simple slice thickening led to a reduction in helical imaging artifacts; however, by definition, this led to a concomitant reduction in z-resolution (Figure 4b-c). Surprisingly, the adaptive-upsampling technique[3] also led to a reduction in z-resolution, despite allowing a "thin-slice" reconstruction with reduced helical imaging artifacts (Figure 4d-e). From the comparison, it was apparent that the data acquired with 128-slice Ingenuity permitted thin-slice reconstruction, without helical imaging artifacts, and without the concomitant reduction in z-resolution observed with the alternative approaches.

Given the superb performance of Ingenuity DAS with respect to slice thickening and previously reported adaptive upsampling techniques, it is also interesting to compare the performance of Ingenuity DAS to that of ZFS systems. System architecture prohibited the simultaneous acquisition of non-Ingenuity, Ingenuity, and ZFS data; therefore, a skull phantom was scanned to allow comparison of the results of the Ingenuity and ZFS techniques. Figure 5 demonstrates the similarity of results achieved with Ingenuity DAS and ZFS.

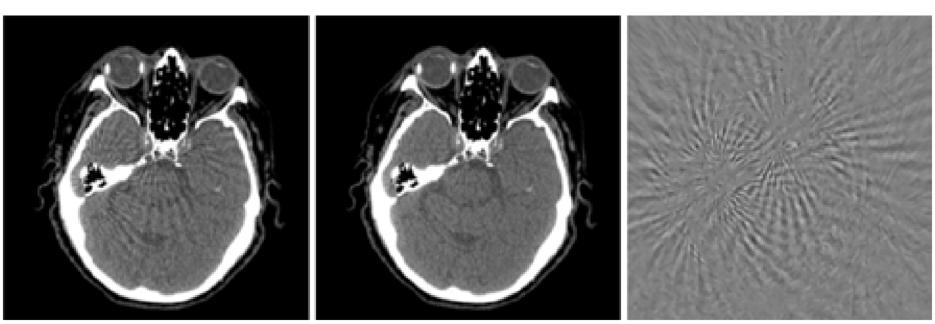

Figure 2: (left) Helical imaging artifacts in a thin-slice (0.67 mm), helical head scan from a 64-slice, non-ZFS, non-Ingenuity system (center) the same image reconstructed from 128-slice Ingenuity DAS demonstrating a substantial decrease in artifact (right) a difference image demonstrating the suppressed artifact (windmill pattern). Note that the difference image also lacks anatomical detail, thus indicating that image resolution was preserved.

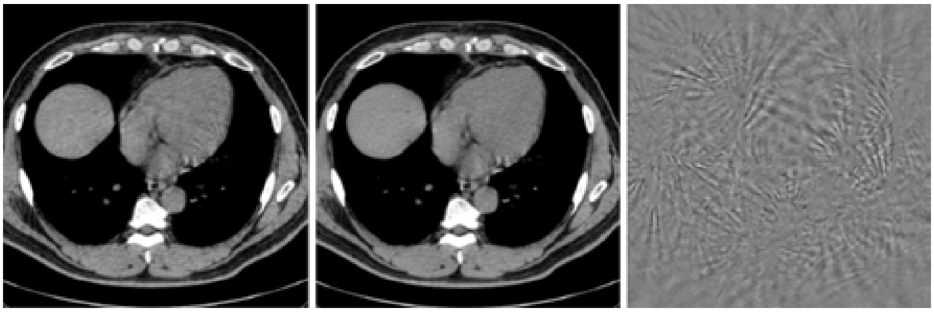

Figure 3: (left) Helical imaging artifacts in a thin-slice, helical chest scan from a 64-slice, non-ZFS, non-Ingenuity system (center) the same image reconstructed from 128-slice Ingenuity DAS demonstrating a substantial decrease in artifact (right) a difference image demonstrating the suppressed artifact (windmill pattern). Note that the difference image also lacks anatomical detail, thus indicating that image resolution was preserved.

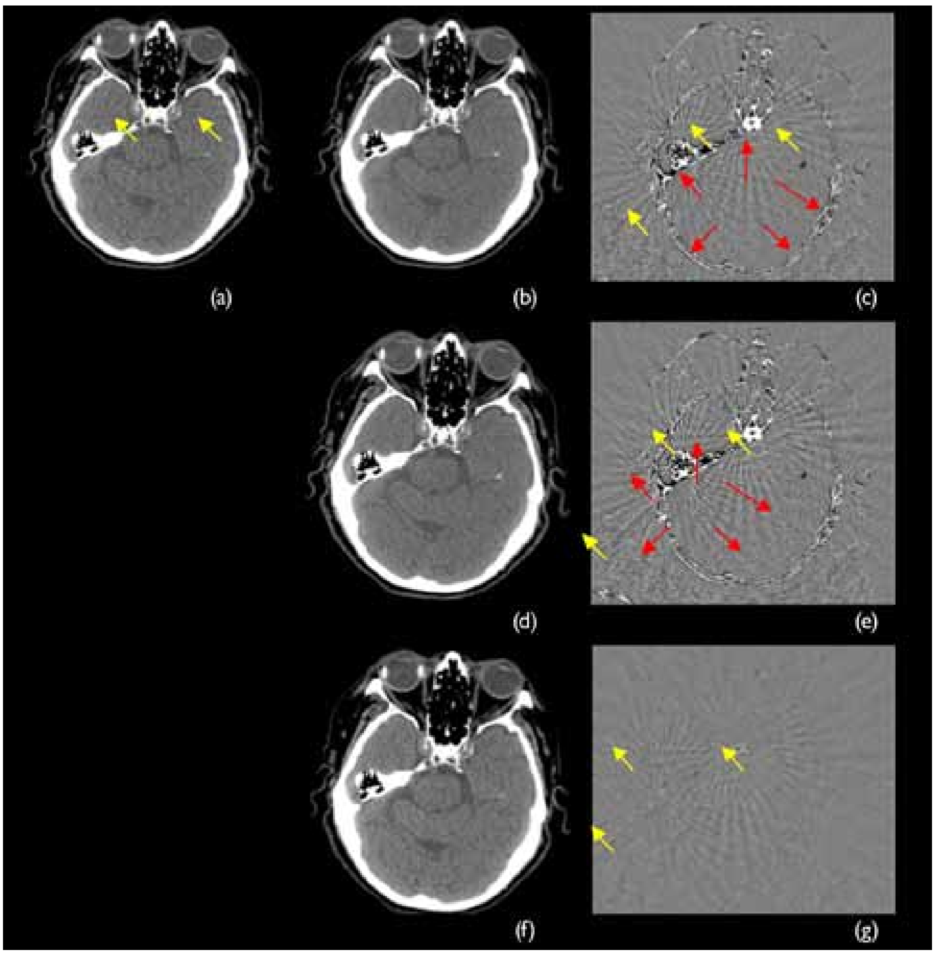

Figure 4: Effects on z-resolution of 3 scanning methods to prevent helical imaging artifacts: (a) Thin-slice reconstruction from a 64-slice, non-ZFS, non-Ingenuity scan exhibiting helical imaging artifacts (windmill pattern, yellow arrows), (b) thicker-slice reconstruction of the same scan demonstrating reduction in helical imaging artifacts (windmill pattern, yellow arrows), (c) difference image showing removed helical imaging artifacts (windmill pattern, yellow arrows), but also reduction of z-resolution demonstrated by the presence of anatomical information (red arrows – notice the skull boundary is clearly visible) in the difference image, (d) Thin-slice adaptive-upsampling reconstruction of the same scan exhibiting reduction in helical imaging artifacts, (e) difference image showing removed helical imaging artifacts (windmill pattern, yellow arrows), but also reduction of z-resolution again demonstrated by the presence of anatomical information in the difference image similar to that of simple slice thickening (red arrows), (f) Thin-slice reconstruction from 128-slice Ingenuity scan demonstrating lack of helical imaging artifacts, and (g) difference image exhibiting removed artifacts (windmill pattern, yellow arrows) without loss of anatomical detail.

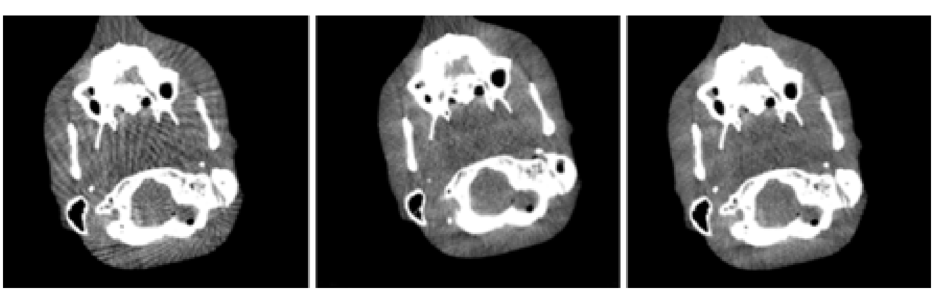

Figure 5: (left) Helical imaging artifacts in a thin-slice, helical scan of a head phantom on a 64-slice, non-ZFS, non-Ingenuity system (center) the same phantom imaged on a 128-slice ZFS system demonstrating a helical imaging artifact suppression (right) the same phantom imaged on a 128-slice Ingenuity system that demonstrates clinically equivalent helical imaging artifact suppression to that achieved with the ZFS system.

Conclusion

Ingenuity Data Acquisition and Sampling provides high-resolution, 128-slice, thin reconstructions that are clinically equivalent to those resulting from ZFS standard resolution acquisitions, that exceed those resulting from ZFS high-resolution and ultrahigh-resolution acquisitions, and that exceeds the quality exhibited by other approaches that have been introduced to reduce helical imaging artifacts or double slices.

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