A Practical Method to Reducing Metal Artifact for Dental CT Scanners

Koji Kobayashi[*1], Atsushi Katsumata[*1], Koichi Ito[*2], Takafumi Aoki[*2]
*1 Research and Development Headquarters, Yamatake Corporation 1-12-2 Kawana, Fujisawa, Kanagawa 251-8522 Japan
*2 Graduate School of Information Sciences, Tohoku University, 6-6-05 Aoba, Aramaki, Aoba, Sendai, Miyagi 980-8579 Japan
kobayashi-koji@jp.yamatake.com

Abstract

An integrated and effective metal artifact reduction method named Metal Erasing (ME) especially suited to dental applications is proposed. Layout of metals is identified as metal-only tomogram, using its characteristics of X-ray opacity and simple image processing technique of binarization together with backward projection. Metal-only sinogram is calculated by forward projection of the metal-only tomogram, and identifies corrupted areas on the original sinogram. The areas are then replaced by interpolation, and filtered back projection (FBP) produces a tomogram without figures of metals. The metals can be reproduced by overlaying already obtained metal-only tomogram utilizing linear characteristics of FBP. It is expected that the ME method can be incorporated into commercial CT scanners easily with reasonable computational overhead.

1. Introduction

X-ray signal strength passed through a material is strongly attenuated if its atomic number is large. For dental CT scanners, metals used for treatments are considered opaque to X-ray beam, because the atomic numbers of the metals are much higher than that of human tissues and bones. The nonlinearity caused by the opacity produces corruption on sinogram. When FBP is applied to such sinogram as reconstruction algorithm, the corruption produces black and white streaks as metal artifact.

When there are multiple metals on a field of view (FOV), strong artifacts are observed at around angles where metals meet or overpass in scan rotation, because thickness of metals changes rapidly. Recent practices of dental implants that needs precise three-dimensional structures of teeth and maxilla makes cone beam CT scanners more popular. Though metal artifact is a general problem among all CT scanners, it is especially important in dental applications.

Many approaches for metal artifact reduction (MAR) are found in literature, however introduction of an effective method to commercial CT scanners have not been known. FBP is widely applied as reconstruction algorithm among commercial CT scanners, because it is fast and provides good quality tomographic images. Reconstruction algorithms other than FBP can be potentially free from metal artifacts. Iterative reconstruction algorithm [1] is known to be the one, however, it is rarely implemented because of its large computational overhead and of poorer quality tomographic images than FBP. Provided that FBP is used, an MAR method has to modify sinogram so as not to generate artifacts by FBP. Precise identification of areas on sinogram corrupted by metals is the next problem. As a geometrical approach, sinusoidal curves on sinogram produced by metal are studied [2]. More elaborately, mechanisms of tomographic projections are used to find layout of metals. Metal corrupted areas are roughly identified on sinogram, and then projected backward to generate a tomogram. A study [3] discusses a method that replaces potentially corrupted areas with zero, and the modified gray scale sinogram is backward projected. In this method, the metal areas may be mixed together with other areas that are zero originally. The metal-only tomogram is forward projected into metal-only sinogram. The values in the identified metal-corrupted areas are replaced by various approaches, such as linear interpolation [4], wavelet interpolation [5] or simple subtraction [6].

We propose an integrated and practical MAR method as Metal Erasing, which identifies precise

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layout of metals by a pair of backward and forward projections. The obtained metal layout is effectively used both for identification of metal corrupted areas, and for reproduction of metals on the final tomogram. In the method, the metals are assumed to be completely opaque to X-ray. Black and white sinogram is produced by binarization with a threshold that separates opaque areas from others. Metal-only image is generated as highest value areas on a tomogram obtained by simple, non-filtered, backward projection of the binarized sinogram, because opaque metals produce consistent sinusoidal curves on sinogram. Some areas other than metals that happen to exceed the threshold are eliminated, because they do not draw complete sinusoidal curve, and therefore, cannot be accumulated to the highest value.

The areas corrupted by metals are identified by the metal-only sinogram calculated by forward projection of the metal-only tomogram. The values on the areas are replaced by linear interpolation. FBP is applied to the modified sinogram, and produces a tomogram without metals. The metal information is added in the sinogram domain, however it is simpler to be in tomogram domain using linear characteristics of FBP.

ME method is actually tested using the raw data obtained from a dental cone beam CT scanner, and its performance has been verified

2. Principles

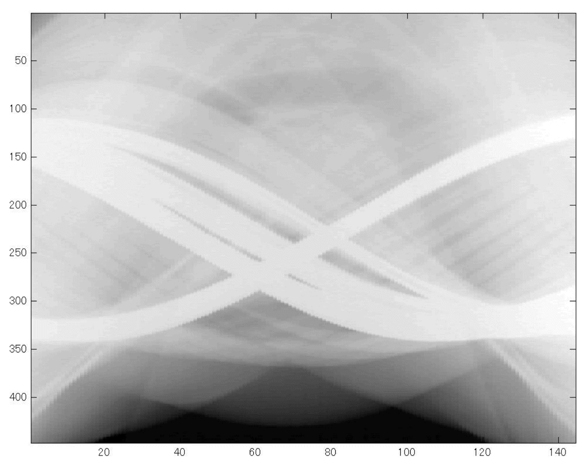
The proposed method consists of following three steps.

Step 1: Identifying Metals

Metal attenuates X-ray beam from all directions if it has some level of volume. A point in the FOV that blocks X-ray from all rotational directions draws a bright sinusoidal curve on sinogram. Now we need a way to find bright and consistent sinusoidal curves on sinogram. Take a line from a sinogram at an angle, project it as a one-dimension function to a reconstruction plane, repeat it for all angles, and a sinusoidal curve always converge at a specific point determined by the radius and the initial phase of the curve. Therefore, metals can easily be identified on the tomogram as areas where their value is at the highest. It should be noted that concave parts of a metal couldn't be reproduced by this method.

Step 2: Interpolation

The metal-only tomogram obtained in Step 1 is forward projected, and metal-only sinogram is



(a) Sinogram

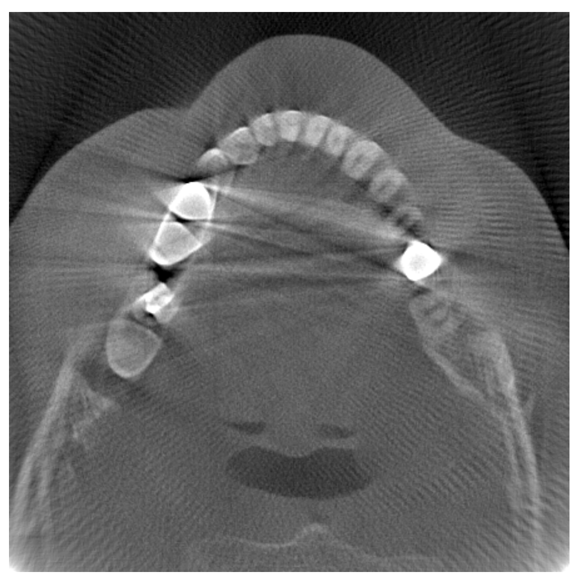

(b) Original Tomogram

Fig.1 Sinogram and its FBP result

calculated. It identifies areas in the original sinogram where their value is corrupted by metals. The values in the areas are replaced by linear interpolation using values of adjacent pixels at the edges of metal corrupted areas at an angle.

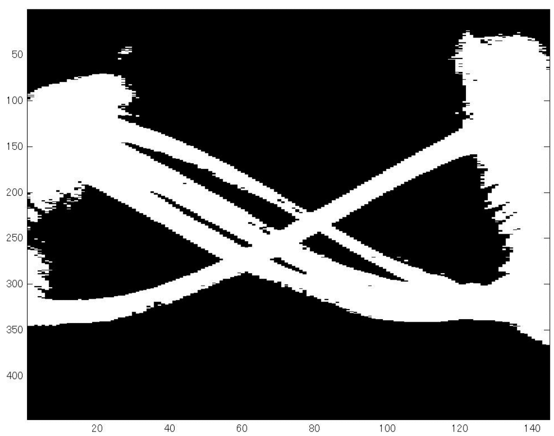
Step 3: Reconstruction

The modified sinogram obtained in Step 2 is backward projected by FBP, and reconstructs a tomogram without figures of metals. For reproduction of metals, linearity of FBP provides two approaches. The metal-only sinogram obtained in the Step 2 is added to the metal-erased sinogram in sinogram domain, or the metal-only image obtained in Step 1 is added to the tomogram without metal in tomogram domain. The latter is apparently simpler than the former.

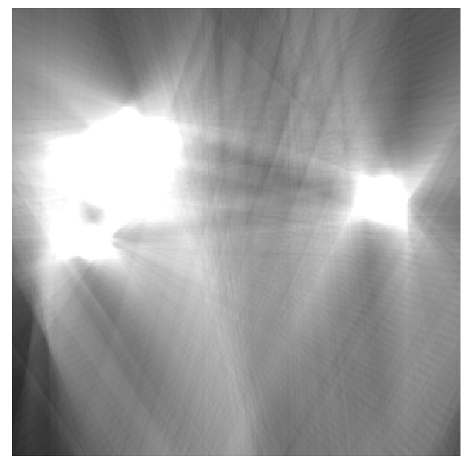
3. Experiments and Discussion

A subject who has typical dental treatments is pictured using a cone beam CT scanner (CB MercuRay, Hitachi Medical Corporation). The scanner produces two types of outputs, volume data as 512 of 512×512 transaxial images, and raw data as 288 of 512 × 512 projection images at 360 degrees. Measurement condition is 120kV and 15mA.

A sinogram is composed of 256th rows extracted

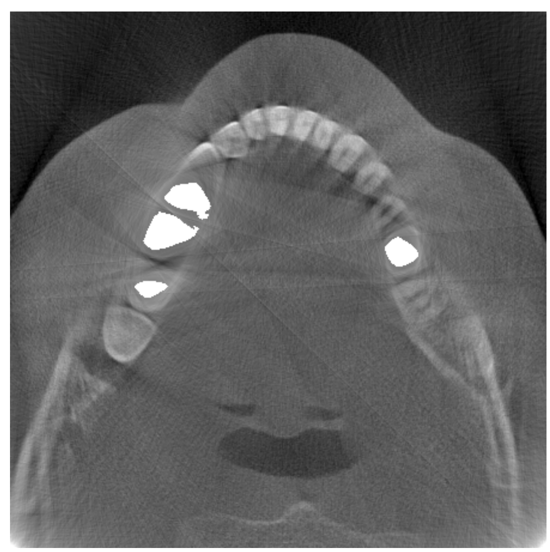


(a) Binary sinogram



(b) Backward projected binary sinogram

(c) Metal-only tomogram



(d) Artifact reduced tomogram

Fig. 2 Example of ME method

from 144 images of the raw data as shown in Fig.1 (a). 144 images are taken out of 288 images for 180 degrees such that the orientation of reconstructed image coincides with that of the transaxial image for comparison purposes. Four bright sinusoidal curves produced by four pieces of metals can be observed. FBP is applied to Fig.1 (a), and a tomogram without metal artifact reduction is obtained as Fig.1 (b). This figure is compared with the 256th image of the transaxial images, and it is observed that its quality is equivalent in terms of metal artifact, regardless of possible differences in the processing methods. Fig.1 (b) shows the sub-maxilla of the subject. It includes four pieces of metals, one each on the second bicuspid, and the first and the second molar tooth on the left, and on the first molar tooth on the right

Fig.2 shows images produced by ME method to the measurement. In Step 1, the sinogram Fig.1 (a) is converted to black-and-while sinogram by binarization as shown in Fig.2 (a). By applying simple backward projection, we get Fig.2 (b). The metal-only image Fig.2 (c) is produced by binarization of Fig.2 (b) that extracts its highest value areas. In Step 2, metal-only tomogram is forward projected in order to identify corrupted areas, and the areas are linearly interpolated. In Step 3, the modified sinogram is backward projected by FBP. Fig.2 (d) shows the resultant tomogram that is an overlay of the tomogram without metal and the metal-only tomogram obtained in Step 1.

Complete sinusoidal trajectory is necessary for any structure to be properly reconstructed. Sinusoidal trajectory of some structure in the vicinity of a metal tends to be overridden by that of the metal, and its structural information is lost at the parts. If some structure looses a part of sinusoidal trajectory, the edge information corresponding to the lost directions cannot be reproduced. Therefore, perpendicular edges against to large metals tend to be lost in the vicinity of the metals. In Fig.2 (d), it is shown that the shapes of the second bicuspid and the first molar tooth in the left are lost from the reason. The shape of the metal is used instead. In dental practices, the size of metal is sometimes smaller than that of a tooth, and contour of a tooth is parallel to that of a metal. In Fig.2 (d), the first bicuspid in the right and the second molar tooth in the left both have smaller metals than the tooth, and their contours are well recovered.

ME method consists of a pair of backward and forward projections, and therefore, it is easy to implement for commercial CT scanners because these projections are familiar routines presumably included in their software library. The major part of processing time of CT scanners is FBP reconstruction. It is estimated that total processing time for CT scanners with ME method are around 2 to 3 times of the original processing time.

4. Conclusion

It has been shown that ME method produces good quality tomogram by precisely identifying metal corrupted areas using a pair of projections, and is effective in that time consuming metal layout is used for dual purposes. The algorithm is easy to implement because it is based on well-accustomed routines for commercial CT scanners. The computational overhead is estimated within reasonable expectations for metal artifact reduced tomograms. Its extensions to a fully three-dimensional method for cone beam CT scanners are the next challenge.

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