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Partial-data interpolation method for arc handling in a computed tomography scanner

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ABSTRACT

X-ray tube arcing in computed tomography scanners causes poor image quality. During the time that the X-ray tube recovers to full voltage after an arc, image data is being collected. Normally this data, acquired at less than full voltage, is discarded and interpolation is performed over the arc duration. We have developed an algorithm that corrects for improper tube voltage, allowing previously discarded data to be used for imaging. The use of voltage corrected data provides improved image quality compared to simple interpolation methods. This improvement is relevant today as the imaging field uses faster scanners with shorter sampling times.

1. Introduction

Despite numerous methods of image reconstruction developed over the years in computed tomography (CT), there has been limited work in interpolation methods specific to X-ray tube arcing. This is primarily due to the fact that standard interpolation methods have typically been effective in eliminating artifacts caused by data loss due to arcing. However, with the continuous drive from the imaging field to have faster scanners with short image acquisition times, adverse effects due to arcing are becoming more significant. Short arc durations are now significant contributors to larger portions of the image data than before and the need to address this is more relevant.

We reviewed existing interpolation methods to look at different ways of dealing with missing data in reconstruction algorithms used in CT since this is also the underlying purpose of our proposed method. There have been methods developed to reduce artifacts caused by missing data such as those proposed for metal artifact reduction [1,2]. These methods successfully lowered artifacts in the images but at times introduced issues like blurring and additional artifacts. Our method specifically addresses reducing artifacts caused in CT scanners by arcing of X-ray tubes. Our premise is that errors will be less if corrected data is used for imaging during an arc rather than assuming a continuous trend and filling in missing data (interpolating).

Section 1.1 of this introduction gives a brief review of arc detection in CT systems. Section 1.2 reviews current methods of dealing with missing data due to arcs. Section 1.3 provides a conceptual overview of our proposed method for reducing artifacts due to arcing. Section 1.4 discusses some of the benefits of our proposed approach to artifact reduction.

1.1. Arc detection in the X-ray CT system

Fig. 1 shows a method used in a Philips CT scanner to detect arcing in tubes. The power supply detects an arc and passes the information to the detection system, which then handles it using interpolation to minimize detrimental effects on image quality.

The tube arc signal becomes active every time the voltage drops below the 90% set point. It remains active until the voltage is above the 90% value again. This signal tells the image reconstruction system when and for how long to perform interpolation during the scan. If an arc occurs during a patient scan, the shutdown of tube power results in a momentary loss of X-rays, and therefore a loss of

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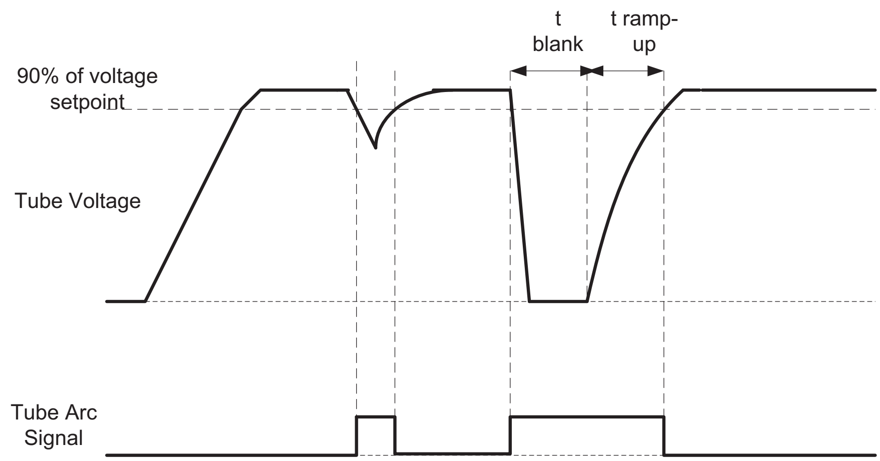

Fig. 1. Arc detection and reporting in X-ray power supply.

imaging data. The length of this momentary period is determined by the time it takes for the power supply's voltage source to recover, which may be on the order of several milliseconds.

Typical image computation or reconstruction algorithms will detect these arc events, and interpolate data during the shutdown period to continue with the patient scan [3,4]. This method can be acceptable from an imaging point of view depending on how long the shutdown period of the system may be and the number of arcs that occur during it. However, the tube voltage recovery time becomes relatively larger compared to scan time in scanners that have high rotation and reconstruction speeds and frequently the artifacts get worse to a level that the image is not acceptable and the patient must be scanned again [5].

1.2. Limitations of current interpolation methods

When a CT scan is performed, data obtained during the scan is used to reconstruct images for the user. The data contains certain information about the scan in the file header, such as the time and position of the X-ray beam when the data is collected. This header also contains a status signal that has information about arcs, as shown in Fig. 1. Common reconstruction algorithms discard data that corresponds to the arc duration and interpolate over it. These methods are usually simple linear or Lagrange methods of interpolation [5,6] depending on the manufacturer.

Our experiments to evaluate limitations of current methods consisted of taking scan data, activating arc status in the header information for some amounts of time, and then reconstructing the image with this data, thus giving an image that would be obtained with real arcing in the scanner. A large number of these simulations were performed to understand the effect of arcing on images with respect to magnitude, duration and other factors.

The simulations were done using the reconstruction routine used by the development team at Philips Healthcare and was implemented in Matlab®. Note that the goal of this project was not to develop a new interpolation algorithm, but to provide a new translation method to generate data during where there would be no data available. This is why we used existing reconstruction methods to do simulations and verifications.

The reconstruction results obtained using current interpolation methods were analyzed to identify areas that could use further improvements. The scans shown in Fig. 2 were done on a 64 slice Philips Brilliance^{TM} CT scanner. The left image is without any arcs, the center image shows the same phantom with 10 arcs, and the right image is the mathematical difference of the two, which shows the artifact caused by the arcing more clearly. The difference image shows undesired streaks and marks (artifacts), caused by arcs. Note that arcing changes the photon output of the X-ray tube, which affects the projections that are acquired by the detectors. The projections, when processed by the image reconstruction system, result in imperfections in image quality. The ultimate acceptability of the images is defined by medical practitioners that use the scanners, but we are able to see from the difference images that interpolation of data during arcing does not eliminate artifacts completely.

1.3. Proposed implementation

Fig. 3 shows a standard arc handling method where data is interpolated over the entire arc duration. We chose to use a common interpolation method that was readily available. The two-data point interpolation shown here is commonly used in industry and is found to be effective in most cases. Fig. 4 shows the proposed method of partial-data interpolation where we use the new algorithm to translate or correct measured data to its equivalent at the programmed voltage during the tail part of the arc event and perform two-point interpolation over the remaining duration. It shows the shutdown period of the power supply where the voltage is zero after which it recovers to its set point. Image data collected during the latter part of the recovery is corrected and used.

Our premise again is that corrected data is more representative of human anatomy than when only interpolation is used without correction, especially when the attenuation is changing rapidly during the arc.

The method to find which points to correct during the arc period was based on selecting a certain threshold of voltage value, which in our case was approximately 60% of programmed value and then correcting data only above that voltage level. We used 60% because we found through experimentation that the signal below 60% would make the signal to noise ratio very low. The 60–90% range allows for the correction of up to 30% of the data in the total arc period. The proposed partial-data recovery is performed in-line with standard interpolation and is a complementary method rather than a replacement for the standard interpolation.

1.4. Potential benefits of partial-data interpolation method

This research introduces a new method of correcting for data loss during arcing on a CT scanner which could provide the following benefits.