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Versatility of OSAR across Medical Imaging Modalities

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***Abstract*—Various forms of artifacts with diverse patterns and combinations can be observed in medical images. These artifacts vary depending on the effectiveness of deep learning-based artifact reduction techniques in medical imaging is determined by factors such as scan setup, equipment quality, patient characteristics, and environmental conditions. However, these methods are limited by their reliance on training data that only covers predefined artifact patterns, making them impractical in clinical settings. This study introduces One-Shot Medical Image Artifact Reduction (OSAR), which seeks to address these limitations. A deep learning approach that maximizes its potential without the need for pre- trained general networks. Specifically, OSAR utilizes synthesized data from the input image during testing to train a lightweight, image-specific artifact removal network. This enables OSAR to effectively address a wide range of additive artifacts present in medical images that may not be represented in existing large training datasets.**

I. INTRODUCTION

Since the advent of CT scans in the 1970s, efforts to enhance clinical image clarity have persisted despite challenges posed by metal artifacts from dental fillings, implants, and surgical clips, which absorb or block x-rays. These artifacts distort images, compromising diagnostic precision critical in cancer treatment planning and orthopedics. Over four decades, research has focused on reducing metal artifacts (MAR) stemming from beam hardening, scatter, noise, and the non-linear partial volume (NLPV) effect. Techniques include using non-metallic implants, adjusting scan parameters, improving raw data, employing iterative reconstruction, and post-processing. This review categorizes MAR methods, identifies six primary approaches, and discusses limitations, offering insights for future progress.

Figure 1 shows that the number of yearly CT MAR articles approximately quadrupled between 2010 and 2015. While a rise in publications is Anticipated as a result of the prevalent "publish or perish" culture in academia, this spike is notably substantial. The heightened research activity reflects a significant dedication to developing effective MAR solutions across a range of applications. Particularly noteworthyis the increase in MAR papers focused on hip and dental implants since 2010, as highlighted in recent times, there has been a noticeable increase in papers related to MAR, as depicted in Fig. 2. specifically addressing radiation therapy, indicating a growing recognition of the necessity for improved techniques toenhance image accuracy in this field. In 2015, radiation treatment applications accounted for around 20% of CT MAR papers, ranking closely behind dental implants, which account for 24%. An analysis of the primary publications representing each of the four MAR method categories provide valuable information about technological trends. Kalender et al. (1987) published a seminal study titled 'Reduction of CT artifacts caused by metallic implants', which established thestandard in the Projection Completion category. It describes a linear interpolation algorithm, which is frequently used as a guide for new MAR techniques. The most-cited work on iterative reconstruction algorithms is Wang et al.'s (1996)

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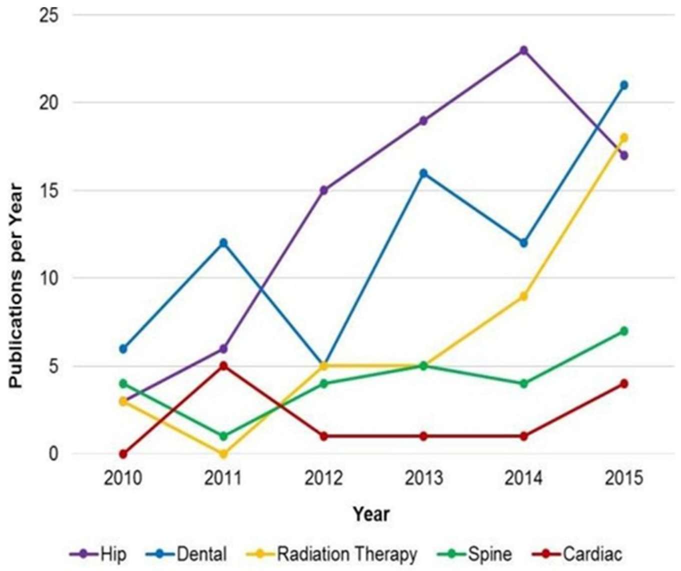


"Iterative deblurring for CT metal artifact reduction." It describes a method for explicitly discarding data hidden by metal objects is handled by estimating new projections based on a deterministic interpretation of the expectation maximization equation. Kachelriess' 2001 paper, "Generalized multi-dimensional adaptive filtering for conventional and spiral single-slice, multi-slice, and cone-beam CT," is the most cited work in the Physics-based Preprocessing MAR category (2014) Noise reduction using adaptive filtering algorithms. Finally, Bamberg et al. (2011), titled 'Metal artifact reduction by dual-energy computed tomography using monoenergetic extrapolation', stands outin the Acquisition Improvement category. It outlines a dual-energy CT (DECT) protocol designed to mitigatebeam hardening artifacts and produce monoenergetic images.and has received 100 citations in less than fouryears since publication.

II. Metal Artifacts

A variety of metal items with different forms and compositions can cause a broad range of abnormalitiesin CT images. These implants have depending on their size and composition, different objects display varyingdegrees of x-ray attenuation and related physical consequences. Smaller and less dense items, such as surgical clips, can produce slight beam hardening or scattering. These effects can be mitigated by performing physics-based pre-processing changes on the data. On the other hand, denser or larger implants, such dental fillings or prosthetic hips, might need the reconstruction algorithm to be adjusted. Statistical iterative reconstruction or the projection completion approach can be used to make this change. Table 1 listsfive types of metal items and describes the associated physical and visual consequences as well as the most applicable MAR techniques.

III. Metallic Object Attenuation Techniques

This review's classification system divides MAR techniques into six categories: approaches like optimizing metal implants, enhancing acquisition, employing physics-based preprocessing, projection refinement, iterative reconstruction, and image enhancement are utilized in addressing artifacts in computed tomography (CT). Methods focused on modifying the reconstruction algorithm are categorized under Projection Completion and Iterative Reconstruction. In a standard CT scan, the system gathers projection data from multiple angles before reconstructing these measurements into an image, employing either filtered back projection (FBP) or iterative estimation. process. All of the attenuation measures obtained for a picture are included in the sinogram. It is impossible to obtain an ideal image in theory because there are only so many individual measurements available. However, using the data at hand, a respectable estimate can be obtained distortions in the projection data emerge whenmetal objects are present in the imaging field, primarilydue to beam hardening, noise, scatter, or the NLPV effect. Anomalies are generated during the reconstruction of images using inaccurate or partial data. To combat these anomalies, several MAR algorithmsare adjusted. the reconstruction procedure itself. One popular method is to immediately replace or repair thesinogram's tainted projection data, frequently via interpolating. An alternative approach uses an iterative process is employed to generate an image using more reliable data by disregarding or statistically mitigating the influence of data affected by the metal object. Pre- processing the data with a model that considers the physical origins of the artifacts can be beneficial. be beneficial for any of these strategies. Adjustments to the reconstruction might not be required in some cases, when this rectification step alone is sufficient. The following section provides a comprehensive overview of each of these groups, their subcategories, and an in-depth examination of the published methods within them.

A. Metallic Implants Enhancement Techniques

Preventing metal from entering the field of view is one of the easiest ways to reduce metal artifacts in CT scans. In clinical settings, this can be accomplished by first choosingnon-metallic implants or by removing metal from the patient. However, because metal removal surgeries are invasive and non-metallic alternatives are scarce, these options are frequently impractical in real life. However, thestudy by Gray et al. shows examples of dental fillings removed to help in radiation therapy planning for cancers located in the head and neck region.. By removing these fillings, streak artifacts were completely eliminated, which greatly enhanced doctors' capacity to distinguish between different head anatomical regions. Apart from removal, the primary focus of studies hasThe focus has been by evaluating image artifacts induced by various metal compositions, researchers aimed to pinpoint the most suitable implants with minimal attenuation. Weeseet al. found that surgical clips crafted from titanium and stainless steel, frequently employed for hemostasis, exhibited notably fewer artifacts compared to tantalum clips. Plastic clips, while not inducing visible artifacts, showed restricted long-term efficacy. Ebraheim et al. subsequently compared stainless steel and titanium screws and bars used for pelvic fixation., concluding that titanium significantly reduced image artifacts while providing comparable fixation and fracture healing quality to stainless steel. Another study by Haramati et al. Comparing addressing artifacts in computed tomography (CT) involves approaches such as optimizing metal implants, improving acquisition, using physics-based preprocessing, projection refinement, iterative reconstruction, and picture enhancement. Methods for altering the reconstruction method are classified as Projection Completion and Iterative Reconstruction. In a conventional CT scan, the system collects projection data from numerous angles before reconstructing the measurements into a picture using filtered back projection (FBP) or iterative estimate.and molybdenum that is being explored as a possible substitute for titanium. These materials' properties are explored; titanium exhibits lesser amounts of artifact. The location of the vitallium between stainless steel and titanium in terms of stiffness, strength, and biocompatibility, displayed medium-level versatility despite its artifact limitations.

B. Acquisition Improvement

One potential approach involves adjusting the CT scanacquisition parameters, including the voltage of the x- ray tube, tube current, scan orientation, and slice thickness. Another innovative technique involves employing dual-energy protocols, which gather material decomposition information using two distinct x-ray spectra. A special technique for differentiating between different energies within a single spectrum is provided by spectral CT, particularly when combined with photon-counting technology.

C. Parameter Adjustment

Preferred gantry angles for imaging or scanning around the metal item are two techniques to enhance data acquisition. In order to avoid metal artifacts in important imaging regions. when they looked into gantry tilt angles for imaging complete knee prosthesis. The angles ranged from 10 to 15 degrees. In their comparison of helical CT and multiplanar reconstruction with conventional CT, Lakits et al. found that helical acquisition greatly enhanced metal object localization and decreased beam hardening artifacts, especially because sagittal plane information was not available. The use of axial imaging for titanium and cobalt-chrome implants has been found to reduce streak artifacts in CT angiography compared to helical scanning, typically used for assessing arteries surrounding aneurysm clips. However, for most applications, the reduction in volumetric coverage provided by helical CT is considered more significant than the enhancement in image quality achieved with axial capture. Tolakanahalli et al. introduced a novel technique for generating digital subtraction angiography-type images using CT with contrast agents byremoving metal objects from the projection data, thereby improving visualization near metal surfaces. Numerous modifications to the scan acquisition process have been introduced to tackle metal artifacts. Link et al. extended the CT scale to diminish artifacts originating from the femur.implants, improving diagnostic capabilities by accurately representing high attenuation coefficient metal objects. Decreasing slice thickness and increasing tube voltage were also explored to enhance diagnostic scores and reduce metal artifacts. Lee et al. examined imaging techniques for the spine following the insertion of pedicle screws. noting that higher tube voltage reduced metal artifacts, while variations in tube current had limited impact on image quality. Increasing the x-ray tube voltage (kVp) and/or current (mA) is a more aggressive technique that produces more photons with higher energy or more photons overall for better penetration through surrounding tissue and metal objects. On the other hand, the patient may receive a higher radiation dosage or see less contrast from these modifications. Megavoltage CT utilizes photon energies reaching up to 4 mega-electron-volts (MV) was used by Schreiner et al. to minimize artifacts surrounding hip implants; however, this method comes with a higher radiation dosage.recovering data lost to photon hunger. Using a similar approach, Jeon et al. demonstrated reducedmetal streak artifacts and increased and signal-to-noise ratios in tomotherapy, in images reconstructed from hybridsinograms containing MV and kilovoltage x-ray data. Each modification to the scanning procedure that enhances metalartifact reduction comes with its drawbacks, often in the form of increased patient radiation dose or reduced image contrast.

D. Bi-Energy Ct

To counteract the effects of beam hardening, dual-energy CThas proven effective by enabling the extraction of monoenergetic sets of data obtained at two different polychromatic beam spectra from scans. Virtual monochromatic spectral (VMS) images, also known as monoenergetic images, can be produced with the use of attenuation coefficients acquired at two energies. Within the last five years, metal screws were scanned at 100 and 140 kVp, and the energies of the standard spectra at those energies were extrapolated in a highly referenced study by Bamberg et al. At the ideal 119.5 keV energy level, our method dramatically decreased artifacts by 48.6%, improving the diagnostic evaluation of the metal surface and the surrounding area. The investigation found that the best extrapolated energy to see screws at was 105 keV. In a subsequent dual-energy CT study, Zhou et al. used higher photon energies ranging from 70 to 190 keV and determined that 130 keV gave the best decrease of metal artifact. Similarly, Meinel et al. obtained comparable results by extrapolating single-energy pictures from a dual-energy technique that included 140 and 100 kVp scans. They discovered that an extrapolated energy range of 100 to 130 keV produced the highest-quality diagnostic pictures for evaluating metal devices in hip and upper leg bone fractures. The median streak intensity decreased, which improved diagnostic quality. Figure 5 exhibits extrapolated VMS pictures that show fewer artifacts as photon energy increases. However, greater energies have downsides, most notably an increased radiation exposure to the patient. Pessi et al. also shown that picture contrast decreased beyond a particular energy threshold, such as 140 keV, but lower energies around 80 keV were more successful in distinguishing soft tissues. Lewis et al. developed the notion of diminishing returns in VMS reconstruction for hip implant imaging. Implying that the contrast-to-noise ratio decreases and metal artifact removal does not improve significantly above 150 keV. To handle response to non-Poisson noise stemming from amorphous silicon (aSi:H) detectors, Sukovic and Clinthorne devised a statistical model to depict noise in dual-energy CT. Their approach involved integrating a penalized weighted least squares (PWLS) objective function with density domain limitations. In high-noise environments, this approach outperforms its dual-energy filtered back-projection counterpart, particularly at low flux rates.

E. Photon-Resolved Ct

Photon-counting detectors have been investigated recently as a possible mitigation technique for metalartifacts. In particular, charge-summing photon- counting detectors are able to distinguish between individual photon energies, which makes them moreeffective at very low photon counts and allows for spectrum reconstruction. A Medipix3RX detector was usedin a study by Rajendran et al. to get spectral CT scans depicting magnesium and titanium scaffolds at various energy levels.. The simultaneous algebraic reconstruction method (SART), which uses oversampling to make up for dead pixels in the detector, was used for data reconstruction. Images with contrast preservation and excellent elimination of metal artifacts were found in the limited In the high-energy spectrum spanning from 50 to 80 keV, Nasirudin et al. employed a photon-counting detector fortheir spectral CT analysis breakup in another study. The obtained data was included into a reconstruction with penalized maximum likelihood. As can be seen, their outcomes revealed a substantial decline in prominent andshadowy streaks in contrast to filtered back-projection (FBP), while also upholding the integrity of structures adjacent to metal boundaries. For teeth and implants, the suggested approach consistently produced attenuation values that were very near to theoretical estimations.

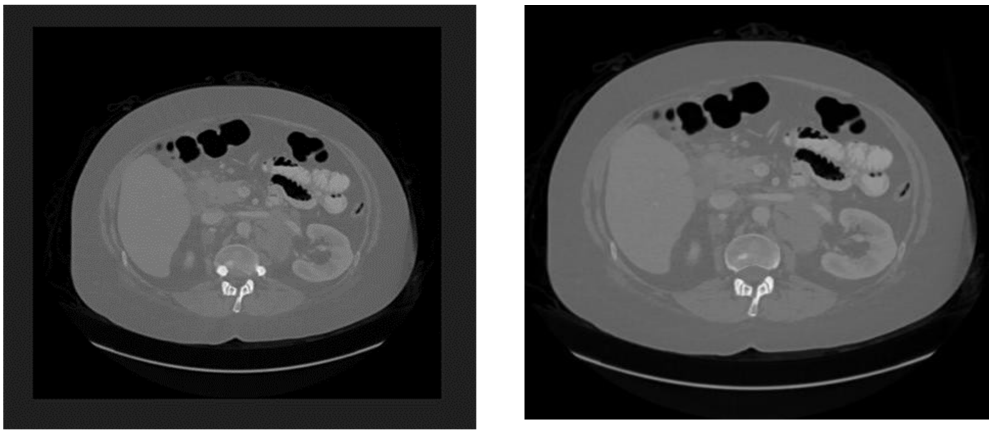
IV. Results and Discussion

This model is crafted to identify and categorize medical chest X-ray images, incorporating both image processing techniques and a convolutional neural network. The accuracy of the model is contingent upon the selection of appropriate threshold values. Throughout each epoch, the data undergoes iterative training to grasp

Loss In Training	Training Accuracy	Loss In Validation	Validation Accuracy
0.4867	0.7924	0.5057	0.7778
0.4816	0.7935	0.4842	0.7845
0.4691	0.8327	0.6458	0.8416
0.4496	0.8615	0.7959	0.8619

Metal Artifact Reduction in X-Ray	Percentage
Atelectasis	24.11%
Effusion	26.56%
Infiltration	36.07%
Mass	12.32%
Nodule	12.87%
Pneumothorax	11.25%

the intrinsic features present within the dataset. Over the past decades, coping metal artifacts in clinical images has been a critical concern, especially in enhancing the quality of computed tomography (CT) scans for diagnostic and treatment planning purposes. Metal items, like dental restorations or implants, pose a significant challenge due to their absorption or blocking of X-rays, resulting in compromised image data and the generation of artifacts during reconstruction. These artifacts, often appearing as bright or dark streaks, not only affect diagnostic accuracy but also hinder the precise differentiation of tissue types, impacting fields like radiation therapy planning and orthopedics.



V. CONCLUSION

Different Metal Artifact Reduction (MAR) techniques frequently have distinct functions. Table 4 provides a thorough analysis of the MAR techniques covered in Section 3, highlighting their applicability for certain metal objects and the related artifacts they aim to target. A major component of MAR approaches are projection completion algorithms, which were mainly created to rectify errors resulting from big or highly attenuating metal items, including dental fillings and prosthetic hips. Algorithms forIterative reconstruction has also been used to reduce Aberrations caused by these implants. For smaller and less attenuating metals, enhancements in acquisition techniques or corrections based on physics principles may be implemented. may suffice; however, other approaches are specifically designed for these types of implants. Despite forty years of dedicated efforts to reduce metal artifacts in Connecticut, particularly since the late 1970s with the pioneering work of Lewitt and Bates, challenges persist, especially with larger, irregular metal components. Hybrid iterative reconstruction emerges as a primary approach, leveraging physical modelsto minimize metal artifacts. Metal segmentation takes place on a first-pass reconstruction picture in the early stages of several MARalgorithms. Accurate segmentation is difficult to achieve because of strong beam-hardening or photon starvation, especially in the vicinity of the metal surface. Three commercially accessible MAR procedures were assessed by Huang et al. using phantoms that represented different types of metal implants. Interestingly, for sizable hip implants, GSI combined with software correction yieldedoptimal reduction of artifacts, showcasing the advantages of dual-energy collection. But existing MAR approaches struggled with complex phantoms, like dental fillings, producing more artifacts without a discernible decrease in the original streaks.

Data segments impacted by metal objects can yield useful information for optimizing metal artifact elimination of Multi-energy scanning methods and prior knowledge of the predicted picture domain are required. Increasing the tube voltage, using several novel techniques are being explored to solve photon starvation and beam hardness caused by x-rays passing through metal objects, such as multiple-energy protocols, high-energy sparse views, and photon- counting spectral CT. To counteract the consequences of beam hardening and photon deprivation, Xi et al. proposed a dual-energy approach with high-kVp, whichinvolves sparse views at 160 kVp or 170 kVp inside a typical 120 kVp scan. This protocol is especially helpfulfor radiation treatment planning.

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