Analysis of X-Ray Beam Hardening Correction Method Relying on Cloud Computing Big Data

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Regarding the correction of X-ray beam hardening in the current CT imaging system, the traditional method will cause the overlapping of images during use, which will gradually harden the beam, and the image reconstructed by the imaging system will gradually become “cup-shaped” or “striped.” “False images” seriously degrade the quality of the images, while causing more interfering diagnostic problems. In this paper, the cloud computing big data analysis algorithm is applied to the X-ray beam hard correction process. According to the transition energy and its energy absorption, the X-ray beam is used as the cut-in point, and the relationship between the attenuation coefficient of similar materials and the X-ray energy is used to remove the artifact image in the initial image reconstruction process to obtain a clear corrected image. Meanwhile, according to the thickness and gray value of the X-ray penetrable object, the result of fitting using a polynomial function is calculated, and an accurate line fitting can be completed for data with smaller coordinates. Finally, the experimental study shows that the cloud computing big data analysis proposed in this paper can detect X-ray beams in real time. This method uses optical receivers to achieve high noise sensitivity to X-rays, and in long-distance transmission scenarios, the bandwidth of communication transmission can be maximized, and different types of formats can be used to complete modulation for different X-rays. Therefore, X-ray beam hardening correction technology has better advantages and the market application scenarios compared with other technologies.

1. Introduction

At present, with the continuous development of optical modulation and demodulation technology, the data information transmission capability of X-ray beams has also been greatly improved. The traditional method used in X-ray detection is to use X-ray on-off to complete the forced modulation of the direct detection (IM/DD) system. The modulation technology used usually requires a rapid “on-off” of X-rays switch capability. However, in the radio communication system, the X-ray phase, frequency, and polarization are gradually used in modulation and demodulation technology without considering the X-ray intensity, which can greatly improve the communication capacity of the limited X-ray channel. Usually, light and electricity belong to one type of electromagnetic wave, so theoretically, the optical communication system can use the same modulation and demodulation technology as the radio communication system. With the continuous development of medical science and technology, cloud computing data analysis technology has been widely used in many fields such as X-ray imaging, medical diagnosis, error-free detection in aviation, optical reverse engineering, and security control [1–3]. The traditionally used CT imaging technology mainly uses the interaction attenuation characteristics between unidirectional X-rays and matter as the premise of the research and converts the image reconstruction problem into the solution of linear correlation problems. However, in the actual use of the CT system, X-rays can be used to make the unidirectional X-rays generated by the electron beam action materials have the characteristics of continuous energy distribution [4–7]. During the X-ray CT imaging process, X-rays have the characteristics of energy spectrum distribution. Generally, the higher the energy, the stronger the...
penetration of X-rays to objects. Conversely, the lower the energy, the weaker the penetration of X-rays into the object [8–10]. In addition, in the case of using the transmittance of light to illuminate the object, the scanning of the polychromatic line through the object reduces the energy absorbed by the object and increases the average energy absorption of X-rays, that is, the hardening of the X-ray beam; assuming that the image reconstruction is conducted by means of image projection data as conventional methods, the physical slices with uniform initial density show the phenomenon of nonuniform gray value in the image reconstruction quality, that is, the “cup-shaped” or “ray-shaped” artifact image [11–13]. The above hardening artifacts have a serious impact on the quality of CT reconstructed images and also hinder the development of CT imaging technology to a certain extent. After the discovery of X-rays, CT imaging technology also developed rapidly and gradually became an advanced nondestructive testing method. It includes the industrial field, medical field, mathematical analysis field, and computer science field. This technology obtains the cross section information of the object by performing radiation detection of different dimensions on the object. Due to the characteristics and advantages of X-ray itself, up to now, domestic and foreign researchers can roughly divide the artifact correction caused by X-ray beam into two categories: one is the combined correction of hardware and software. Using hardware, the water bag method used in the early days can be compared with the more popular filtration method. The software correction is mainly divided into two processes: preprocessing and postprocessing. In the early stage, multicolor projection technology is mainly used to achieve linearization, especially for a single material; the cup-shaped artifact effect is significant. For example, the preprocessing correction method proposed by Herman mainly uses the export device to realize the image reconstruction of energy projection, but the latter usually uses an iterative method for complex CT test targets, most of which require existing knowledge in the X-ray beam hardening correction process or are applied to objects with simple compositions. However, due to insufficient existing knowledge, it is more difficult to correct beam hardening artifacts in CT imaging technology [14, 15].

In this paper, by effectively combining the principle of CT ray beam processing and fully analyzing the influence of beam hardening on image projection, a corresponding beam hardening correction model is constructed, and this model is used to realize the premathematical analysis of image projection data, which can be used to effectively obtain positive group image of X-ray beam hardening. Using the linear correlation of the initial image as the basis of image reconstruction, the optimal solution of the weighting coefficients in the linear combination can be obtained.

2. X-Ray Beam Hardening Correction Model

Assuming that $P$ is the initial projection that can be obtained in the X-ray environment and $P'$ is the projection data obtained after $P$ has been corrected, the relationship between $P'$ and $P$ can be expressed as follows:

$$P' = S(P).$$

In the formula, the $S$ table seems to be a precorrection function. According to the detailed analysis above, the beam hardening of X-ray has a great influence on the projection value. If $S_n(P) = p^n (n \in N^+)$, the fitting correction curve can be obtained by using the polynomial $S(P) = \sum S_n(P) (n \in N^+)$. From the analysis of Figure 1, it can be seen that the curve obtained after the projection value is processed by $S(P)$ conversion; according to the different values obtained by $n$, different values of $S_n(P)$ can be obtained. For the correction of projected values at different levels, the lack of correction and overcorrection will occur. The weighted solution and postprocessing of $S_n(P)$ can be used as the final pre-processing projection data analysis, which can be expressed as follows:

$$S(P) = \sum_{n=1}^{N} c_n S_n(P) = \sum_{n=1}^{N} c_n P^n.$$

The corresponding image is reconstructed according to the projection data obtained by preprocessing, which can be expressed as follows:

$$f_n(r) = R^{-1} S_n(P).$$

According to the above expression, $R[8]^{-1}[Sa]$ represents the inverse transform of Radon; $f_n(r)$ represents the function used in the three-dimensional space of the image; $r \in R^3$, and $r = (x, y, z)$. Then, the reconstructed image obtained finally can be expressed as follows:

$$f(r) = R^{-1} P' = R^{-1} S(P) = \sum_{n=1}^{N} c_n f_n(r).$$

The final image reconstruction can be obtained by linear combination of the basic image and calculated according to
the minimum value of TV obtained by the coefficient \( c \) in the
expression processed by the function \( f(\tau) \).

The TV value is an important benchmark for evaluating
image sliding and can be used to achieve effective noise
suppression. X-ray beam artifacts cause large noise inter-
ference to CT images and seriously affect the smoothness of
images. Therefore, in this paper, the colossus TV, which is an
object function, reconstructs the image of the expression
equation (4), so that the TV value corresponding to \( f(\tau) \)
reaches the optimal value, which can be solved by the ex-
pression as follows:

\[
c = \arg \min \left\{ \int G(c, \tau) d^3 \tau - a \cdot c \right\}.
\]  

(5)

\[
G(c, \tau) = |\nabla f| = \sqrt{(\partial_x f)^2 + (\partial_y f)^2 + (\partial_z f)^2}
\]

(6)

\[
G(c, \tau) = \sqrt{\partial_x f^2 + \partial_y f^2 + \partial_z f^2}
\]

(7)

\[
M_i(c, \tau) = \partial_x f_i(\tau)(\partial_x f(\tau)) + \partial_y f_i(\tau)(\partial_y f(\tau)) + \partial_z f_i(\tau)(\partial_z f(\tau)),
\]

(8)

\[
M_{ij}(c, \tau) = (\partial_x f_i(\tau))(\partial_x f_j(\tau)) + (\partial_y f_i(\tau))(\partial_y f_j(\tau)) + (\partial_z f_i(\tau))(\partial_z f_j(\tau)).
\]

Then,

\[
G^2(c, \tau) = \sum_{i=1}^{N} c_i M_i(c, \tau) = \sum_{i=1}^{N} \sum_{j=1}^{N} c_i c_j M_{ij}(c, \tau).
\]

(9)

\[
\int G(c, \tau) d^3 \tau = a \cdot c.
\]

(10)

\[
\int G(c, \tau) d^3 \tau = \frac{\sum_{i=1}^{N} c_i M_i(c, \tau)}{G(c, \tau)} d^3 \tau = a \cdot c.
\]

(11)

According to expression (11), we can get

\[
a_i = \int \frac{M_i(c, \tau)}{G(c, \tau)} d^3 \tau.
\]

(12)

Assume \( B_{ij} = \sum_{i=1}^{N} \sum_{j=1}^{N} c_i c_j M_{ij}(c, \tau)/G(c, \tau) d^3 \tau \), then it can be obtained according to expression equation (11): \( B = a \cdot c \). So, \( c = B - 1 \cdot a \). The linear system \( c = B - 1 \cdot a \) can be calculated by the iterative method.

(1) Assign an estimated value \( \hat{c} \) to find \( c \).

(2) Use the constraint condition \( ac = \text{con} \). The first step is to modify the required \( c \).

(3) Substitute the modified \( c \) into equation (5) to con-
tinue to the next iteration.

(4) Repeat steps 2 and 3 to correct the estimated value
until the value \( C \) reaches the convergence condition.

3. X-Ray Beam Hardening Correction Analysis

According to the basic reasons for the generation of X-rays,
in the X-rays generated by the electron beam targeting
practice, the energy spectrum distribution curve of the ra-
diation generated by the toughness is continuous. The low-
energy photons whose energy changes are constantly
approaching 0 are mainly due to the inherent limited fil-
tering of the target raw material and the ray, which approach
0 according to the distribution ratio of the energy spectrum
in the process of the energy absorption energy spectrum. If
the photon energy increases, the proportion of the energy
spectrum distribution will gradually change from large to
small; if the maximum energy is reached, since the proba-
bility of electrons directly hitting the target nucleus is low,
the proportion of the corresponding photons is also close to
0, which needs to realize assumptions under reasonable
circumstances. Due to the generation of strong radiation, the
energy spectrum shows that the photon ratio at the 0-energy
end and the high-energy end is almost 0, and no special case
occurs, where the photon ratio decreases smoothly and
slowly in other energy bands, and the photon ratio changes.
X-rays can uniformly pass through the physical intensity
attenuation formula, under the premise of combining the
building law, using the following expression:

\[
I_1 = I_0 e^{-\mu x}.
\]

(13)

\( I_0 \) in the equation represents the initial intensity of the
X-ray. \( I_1 \) reaches the radiation intensity of the reference
X-ray; \( \mu \) represents the material attenuation coefficient,
which is related to the material density and radiation energy.
\( X \) represents a material object length of radiation utilization.
Then, according to expression equation (13),

\[
\mu x = -\ln \frac{I_1}{I_0}.
\]

(14)
In $I_1/I_0$ represents the conventionally used projection data $P$, equation (14) can be transformed into

$$P = \mu x.$$  \hspace{1cm} (15)

Since the material attenuation coefficient $\mu$ in the above equation is a constant, through X-ray analysis, a linear correlation feature between the projection data and the line pass thickness is obtained.

However, under this condition, X-ray can be obtained according to expression equation (13):

$$I_1 = I_0 \int_S S(E) \exp \left( \int_x \mu(x', E) dx' \right) dE.$$ \hspace{1cm} (16)

In the expression, $S(E)$ as the photon density function $\mu(x', E)$ of the incident spectrum shows the linear attenuation coefficient of the physical energy $E$ at the point $x$ on the detected measurement section. The formula for the X-ray projection value is as follows:

$$Q = \ln \left( \frac{I_1}{I_0} \right) = -\ln \int_S S(E) \exp \left( \int_x \mu(x', E) dx' \right) dE.$$ \hspace{1cm} (17)

According to expression equation (17), it can be obtained that if the X-ray can achieve multienergy spectral distribution, the relationship between the projection data and the thickness of the light passing through the material can represent a nonlinear relationship. Figure 2 shows a schematic diagram of the relationship between the two.

According to the analysis of the results in Figure 2, when the solid line represents the relationship between the image data under unidirectional X-ray and the thickness of the penetrating object, the curve is a straight line whose inclination is not 0. The dashed line in the figure represents the curve between the data obtained by X-ray projection and the transmission thickness under multispectral conditions, which is a single ascending curve with decreasing slope. According to Figure 2, it can be concluded that due to the hardening effect of X-ray beam, the function value of dotted line always does not exceed the function value of the solid line. At the same time, with the continuous decrease in X-ray penetration thickness, the two curves will be more remote. With the increase in projection thickness, the influence value of projection will also increase. The goal of achieving beam hardening correction can be based on the maximum value of the actual projection process. Under the condition of keeping the smaller projection value unchanged, the beam hardening correction can be used to realize the quantitative analysis of the influence value of the projection. According to the Monte Carlo simulation rule, it can be concluded that on the basis of realizing the effective analysis of the number of photons, the thickness size of all materials contained in the scanning process can also be tested.

As for the wavelength of light, the modulation device controls the change of the optical phase by using the waveguide structure of the electro-optic material to change the voltage across the material. As shown in Figure 3, the optical phase output from the modulator is proportional to the voltage applied across the material electrodes, as shown in Figure 3. The binary phase shift keying signal with the phase difference can be obtained by adjusting the voltage to obtain the binary phase shift keying signal with a phase difference of 90° in Figure 3. In a multivalued signal transmission system, the greater the distance between symbols, the lower the degree of mutual interference between signals, which is beneficial to the realization of large-capacity long-distance signal transmission. In order to obtain X-rays with a difference of 180°, the value of the voltage applied across the electro-optic material needs to be properly controlled.

Each object has a unique organizational structure, but the atomic structure associated with X-ray emission is characterized by the energies that exist in different electron shells within the atom. If a certain level of energy is reached, the electrons will knock out the K-layer electrons of the material on the target surface, which can ensure that the electrons are in a K-excited state, and the corresponding outer-layer electrons will jump to the K-layer to ensure that they reach a stable state. The remaining energy can be emitted according to the photon mode. This emission is called K radiation in this paper. There are also L radiation and M radiation. Because the quality of the target material is different, the structure of the corresponding atomic material is also different. Different electron excitations will lead to different voltages, and the radiated photon energy will also be different. However, external voltage changes will lead to changes in X-ray spectral characteristics, which will have a certain effect on the intensity of radiation.

When analyzing the absorption of a certain substance to different energy rays, it can be found that there is a law as shown in Figure 4. The target material tungsten (symbol W, atomic number 74) commonly used in high-energy linear accelerators is selected here. It can be seen from the figure that in addition to the curve that the absorption coefficient and energy change continuously together, there is also a sudden change in the absorption coefficient, that is, K-time, L-time, M-time, and other multistage migrations, and the corresponding energy is, respectively (unit: MeV):

- $M_5$: 1.80920E – 03;
- $M_4$: 1.87160E – 03
According to the analysis in Figure 4, the X-rays generated by the target surface can absorb the low energy. Among the different types of materials selected, the W type has the best effect, the effect of Gd is better than that of Fe, and the absorption effect of Pb is the worst in the low-energy state, but in the high-energy state, the absorption material is better, and it will also affect the radiation intensity of high-energy X-rays. Al has the worst energy absorption ability, so it is the best choice to choose a material similar to the target surface material as the filter. After the material selection is completed, the thickness of the selected material needs to be confirmed, which will need to determine the intensity change of the X-ray through processing and filtering according to the actual application. The energy spectrum used in this paper is EGSnrc software, which mainly includes the energy spectrum generated by 10 MV aluminum target, the filter plate is made of aluminum, and the thickness is 5 cm, 10 cm, and 20 cm, respectively.

According to Figure 5, it can be concluded that the thicker the selected filter is, the stronger the energy absorption capacity will be. When the thickness of the filter is about 20 cm, the ray intensity changes of the energy obtained by 10 MV will be less than 30%. At this time, the absorption effect of low energy is better, and the radiation with lower energy can be absorbed as much as possible, but it will also seriously affect the intensity of the rays and also affect the performance and test accuracy of the CT machine to a certain extent. However, when the thickness of the filter is 5 cm, most of the X-rays can pass through, but to a large extent, the low-energy rays will be absorbed, and the degree of hardening of the rays cannot be reduced more effectively.

Considering the above factors, a 10 cm-thick aluminum is used as the filter for the energy spectrum generated by the 10 MV aluminum target, which can not only absorb the lower energy part of the high-energy spectrum well but also allow most of the high-energy rays to pass through (the intensity change is 50% about) (Figure 6).

### 4. Analysis of Experiment and Results

In order to verify the improvement effect of the above filter element hardening, the two kinds of energy spectrum radiation are analyzed based on cloud computing big data and compared with the monochromatic ray projection with energy of 2MeV, as shown in Figure 7. It can be seen from the figure that the projection presents a nonlinear change when no filter is applied, and the ray hardening phenomenon is very obvious. After applying the aluminum filter, the relationship between the resulting polychromatic projection and the thickness of the scanned material is close to a linear change, reducing the hardening effect.

In order to accurately calculate the effects of the above two types, the relationship area between polychromatic projection and monochromatic projection can be considered, as shown in Figure 8. If no filter is added, then the projection generated by the X-ray spectrum will be reconstructed, resulting in hardening artifacts, and the similarity expression using the hardening correction method proposed in this paper is as follows:
According to the above expression, the data processing speed and storage space of the computer can be limited during the CT imaging process, which will lead to a decrease in the reconstruction rate, but the projection and monochromatic projection obtained by the prefilter after processing will undergo a better linear change, and an approximate linear relationship between the two is obtained as follows:

\[ m = -0.0044p^3 + 0.0887p^2 + 0.6848p, \]
\[ R^2 = 0.9998, \quad (18) \]

According to the theoretical knowledge of image reconstruction, the processing of the linear change of the test data does not affect the result of the image reconstruction.

\[ m = 1.2317p, \]
\[ R^2 = 0.9998. \quad (19) \]

According to the above expression, the data processing speed and storage space of the computer can be limited during the CT imaging process, which will lead to a decrease in the reconstruction rate, but the projection and monochromatic projection obtained by the prefilter after processing will undergo a better linear change, and an approximate linear relationship between the two is obtained as follows:

Therefore, the CT reconstruction using the multicolor projection after adding filters can obtain a good image effect.

5. Conclusion

Since many artifact processing methods are exposed in the process of X-ray beam hardening, the existing mathematical methods cannot be effectively processed, and it is difficult to find an effective solution. Therefore, reducing the artifacts in the CT image processing process has become a challenging work. In view of the problems in the X-ray beam hardening correction process, the artifact image and the image information obtained after correction can be obtained by using metal materials. The X-ray beam correction method proposed in this paper mainly uses the efficient reconstruction of the image in the segmented metal area, effectively calculates the approximate projection and correction image of the artifact image, and realizes the physical feature processing and detailed data analysis of the generated image. Combining the results of CT hardening correction analysis.

**Figure 5:** Absorption curves of low-energy line energy (tungsten target stepping energy) of some materials.

**Figure 6:** Energy absorption below 10 MV when the thickness of aluminum filter is different.

**Figure 7:** Projection comparison when the scanning material is Fe.

**Figure 8:** Relationship to monochromatic projection.
to reconstruct the preprocessed images, clear images can be obtained and the reconstruction of CT images can be achieved to a certain extent. The analysis of the experimental results shows that the X-ray beam detection method proposed in this paper can modulate and demodulate the data information of the carrier signal in its corresponding amplitude, frequency, and polarization direction and can effectively improve the detection capability of X-ray beam and increase the capacity of the communication system.

**Data Availability**

The data used to support the findings of this study are available from the corresponding author upon request.

**Conflicts of Interest**

The authors declare that there are no conflicts of interest.

**References**


