

3D CT Baggage Image Enhancement Based on Order Statistic Decomposition

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Abstract—Baggage scanning systems are widely used at security checkpoints in airports for homeland security applications. However, the CT baggage images suffer from background noise and the presence of low contrast. To address this problem, this paper introduces a new 3D CT baggage image enhancement algorithm using order statistic decomposition. Computer simulation and comparisons are given to demonstrate the excellent enhancement performance of the presented new algorithm and its capability of significantly improving visual quality of CT images while removing the background noise.

Keywords- CT baggage image; 3D image enhancement; order statistic decomposition

I. INTRODUCTION

Baggage scanning systems are widely used for detecting the presence of explosives and other prohibited items in baggage at security checkpoints in airports [1, 2]. However, the CT baggage images contain projection noise and are of low resolution. Such systems use computerized tomography (CT) scanning systems to scan and screen packages and luggage. The systems expose the baggage to X-rays and measure the amount of radiation absorbed by the baggage. 3D CT images of the baggage and items contained inside the baggage are then generated from these X-ray projection densities. These 3D CT images help the security officers visually recognize all suspicious items inside the baggage without manually opening the luggage.

However, these CT baggage images are visually very dark and the details of objects or regions in images are unrecognizable. Moreover, the CT baggage images may also contain a lot of background noise and present low contrast due to the X-ray projection and the limitations of the system hardware [3]. All these result in images with very low visual quality and therefore need to be improved. Image enhancement is an effective tool to improve the visual quality of the images without requiring modifications to the system hardware or the image acquisition process.

Many algorithms have been developed to enhance 2D and 3D image enhancement. Examples include nonlinear filtering [4-6], histogram equalization [7, 8] and unsharp masking [9-11].

In this paper, we introduce a new 3D CT images enhancement algorithm based on order statistic decomposition

for homeland security applications. The algorithm first uses order statistic decomposition to remove background noise from the original CT image slices. Any enhancement algorithm is then used to enhance these denoised image slices. The resulting enhanced 3D baggage CT images are obtained by combining all enhanced image slices. The new enhancement algorithm can improve the global contrast of the images while reducing the effect of projection noise.

The rest of this paper is organized as followed. Section II analyzes the characteristics of the CT baggage images. Section II presents the order statistic decomposition. Section IV introduces the new 3D CT baggage image enhancement algorithm. The simulation results and comparison are discussed in Section V. A conclusion is made in Section VI.

II. CT BAGGAGE IMAGE ANALYSIS

The 3D CT baggage images are 16-bit data which are generated by an X-ray scanning system. Each image contains hundreds of image slices. Each image slice can be considered as a 16-bit 2D image.

Figure 1 shows two examples of CT baggage image slices and their pixel intensity distributions in the column direction. Most of regions in the image slices are visually very dark, especially the non-object regions.

The objects are concentrated in a small area in the image slice and are visually very dark. The details of the objects are completely unrecognizable as shown in Figure 1(a)-(b). Only a few skeletons of objects with high intensity values are visible.

From the pixel intensity distributions of the images shown in Figure 1(c)-(d), the object region contains all of the pixels with high intensity values. It is possible to segment the objects from the original CT baggage images according to different intensity levels. A small number of pixels with very high intensity values in a very large dynamic range significantly expand the data range of the entire images. This is the reason why CT baggage images are visually dark. Image pixels in the non-object regions in images have non-zero intensity values. This observation shows that the CT images present a lot of background noise. It can be further verified by the enhanced results in Figure 2.

Figure 2 shows two enhancement results of CT baggage image slices by histogram equalization. The enhanced results in

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Figure 2(c)-(d) show that the histogram equalization process enhances the background noise while improving the contrast of images. The results further demonstrate that the CT baggage images contain a lot of background projection noise.

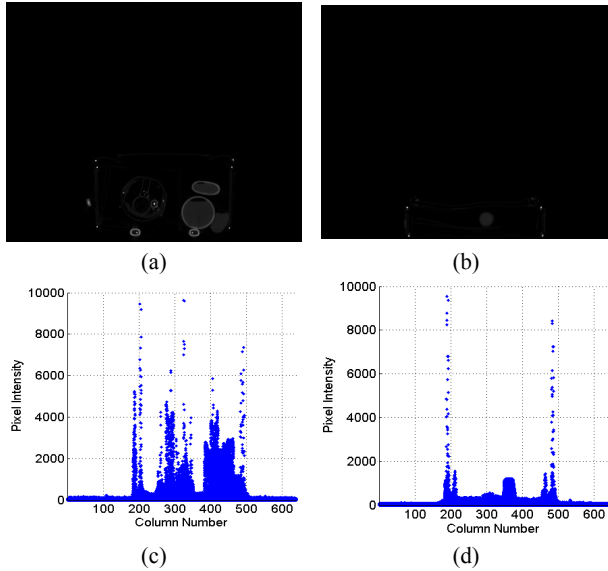


Figure 1. CT baggage image slices and their pixel intensity distribution in the column direction. (a) Original CT image slice #1; (b) Original CT image slice #2; (c) the pixel intensity distribution of (a) at the column direction; (d) Pixel intensity distribution of (b) at the column direction.

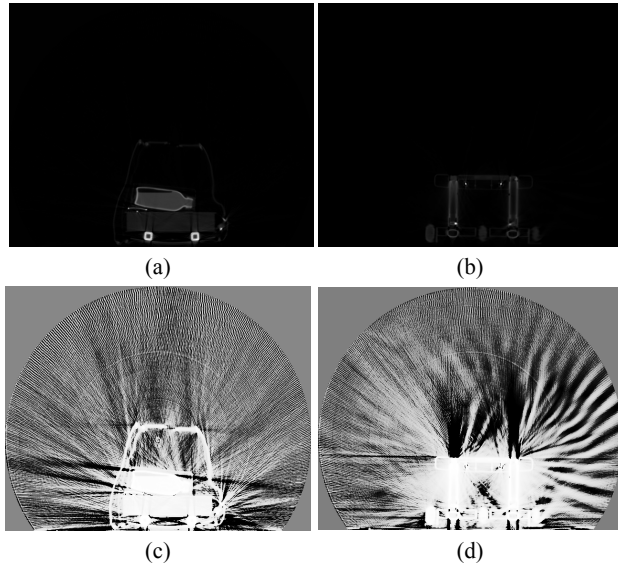


Figure 2. CT baggage image slices and the enhanced results by histogram equalization. (a) Original CT image slice #3; (b) Original CT image slice #4; (c) The enhanced image of (a); (d) The enhanced image of (b).

In summary, according to the analysis, two problems in the CT images need to be solved: (1) The CT baggage images contain a lot of background projection noise; (2) The CT baggage images are visually very dark. In Section IV, we will introduce a new 3D image enhancement algorithm to address these problems.

III. ORDER STATISTIC DECOMPOSITION

In this section, we review the definition of the order statistic and then use it as a parametric thresholding technique for image decomposition, called order statistic decomposition (OSD).

A. Order Statistic

Let $X = (X_1, X_2, \dots, X_n)$ be random variables, if they are arranged in ascending order of magnitude [12],

$$X_{(1)} \leq X_{(2)} \leq \dots \leq X_{(n)} \quad (1)$$

$X_{(r)}$ is called the r^{th} -order statistic.

Thus, the minimum, maximum, and median value of variables, X_{\min} , X_{\max} , and X_{med} are defined as followed respectively,

$$X_{\min} = X_{(1)} \quad (2)$$

$$X_{\max} = X_{(n)} \quad (3)$$

$$X_{\text{med}} = \begin{cases} X_{(k)} & \text{for } n = 2k + 1 \\ \frac{X_{(k)} + X_{(k+1)}}{2} & \text{for } n = 2k \end{cases} \quad (4)$$

B. Order Statistic Decomposition

Based on the definition of the order statistic, it can be used as a parametric thresholding for image decomposition.

For an input image, $I(m, n)$, the maximum, median and minimum value of the input image are I_{\max} , I_{med} , and I_{\min} respectively. We first group its pixel intensity levels into the matrix X , and sort them in ascending order of values, i.e. $X_{(1)} \leq X_{(2)} \leq \dots \leq X_{(n)}$. The r^{th} -order statistic refers to the r^{th} intensity level of the image. The r^{th} -order statistic can be used as a threshold value for image decomposition. The order number r is a parameter which changes the threshold value within the entire data range of the image, namely, $I_{\min} \leq X_{(r)} \leq I_{\max}$.

The image decomposition process separates the input image into two sub-images, $I_1(m, n)$ and $I_2(m, n)$. One sub-image, $I_1(m, n)$, contains all pixels whose value is greater than or equal to the threshold. The other sub-image, $I_2(m, n)$, contains the pixels whose value is lower than the threshold. The order statistic decomposition is defined by,

$$\begin{cases} I_1(m, n) = I(m, n) & \text{for } I(m, n) \geq X_{(r)} \\ I_2(m, n) = I(m, n) & \text{for } I(m, n) < X_{(r)} \end{cases} \quad (5)$$

where $X_{(r)}$ is the r^{th} -order statistic of the input image, and $I_{\min} \leq X_{(r)} \leq I_{\max}$.

The order statistic decomposition will be used for image denoising and enhancement in the new enhancement algorithm presented in Section IV.

IV. NEW 3D CT BAGGAGE IMAGE ENHANCEMENT ALGORITHM

To address the two problems mentioned in Section II, we introduce a new 3D CT baggage image enhancement algorithm using order statistic decomposition.

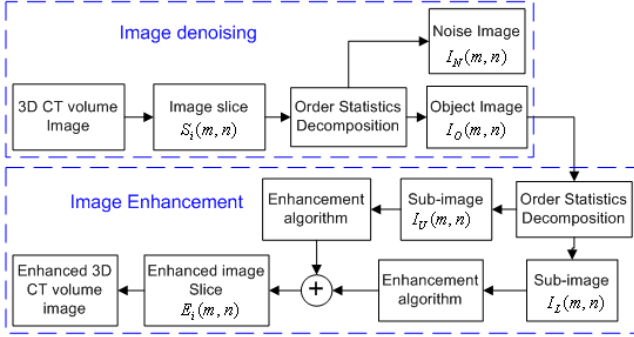


Figure 3. Block diagram of the new 3D CT baggage image enhancement algorithm.

The new algorithm is shown in Figure 3. It enhances the 3D CT volume images by enhancing each image slice individually and then combining them to obtain the final enhanced 3D CT volume image. The new algorithm contains image denoising and image enhancement processes. The underlying foundation of the new algorithm is to employ an image decomposition process to remove the background noise and an enhancement process to improve the visual quality of images while significantly narrowing down the image data range.

The algorithm first decomposes the 3D CT volume image into image slices, and removes their background noise using order statistic decomposition, namely,

$$\begin{cases} I_O(m, n) = S_i(m, n) & \text{for } S_i(m, n) \geq X_{(r)} \\ I_N(m, n) = S_i(m, n) & \text{for } S_i(m, n) < X_{(r)} \end{cases} \quad (6)$$

The object image, $I_O(m, n)$, consists of pixels with intensity value greater than or equal to the r^{th} -order statistic, $X_{(r)}$. Other pixels with the intensity value lower than $X_{(r)}$ will be considered as the background noise.

We only enhance the object image, $I_O(m, n)$. We use another order statistic decomposition to separate the object image into two sub-images, $I_U(m, n)$ and $I_L(m, n)$, namely,

$$\begin{cases} I_U(m, n) = I_O(m, n) & \text{for } I_O(m, n) \geq X_{(t)} \\ I_L(m, n) = I_O(m, n) & \text{for } I_O(m, n) < X_{(t)} \end{cases} \quad (7)$$

The sub-image, $I_U(m, n)$, consists of pixels with intensity value greater than the t^{th} -order statistic. This sub-image contains a very few number of pixels with very high intensity values. The enhancement process simple set all non-zeros pixels in this sub-image to the threshold value, $X_{(t)}$, namely,

$$E_U(m, n) = X_{(t)}, \text{ for } I_U(m, n) \neq 0 \quad (8)$$

On the other hand, the sub-image, $I_L(m, n)$, consist of other pixels with intensity level lower than the t^{th} -order statistic. It contains all informative pixels of the objects. These pixels are located within a desirable intensity range. We only enhance this sub-image by using an enhancement algorithm. Let $E_L(m, n)$ denote the enhanced sub-image. Any enhancement algorithm can be used here for image enhancement. In this paper, we simply select histogram equalization as an example of the enhancement algorithms to enhance this sub-image, $I_L(m, n)$.

The enhanced image slice is then obtained, namely,

$$E_i(m, n) = E_U(m, n) + E_L(m, n) \quad (9)$$

In this way, the data range of the enhanced image slices is significantly narrowed down. The enhanced volume image is then obtained by combining all enhanced image slices.

V. SIMULATION RESULTS AND COMPARISON

The presented 3D CT baggage image enhancement algorithm has been successfully applied to more than 20 CT baggage images. To show its enhancement performance, this section provides the enhanced results of seven 3D CT baggage images. In order to minimize the dark background of CT images, we cropped the object regions from the original 3D CT baggage images and apply enhancement algorithms to them.

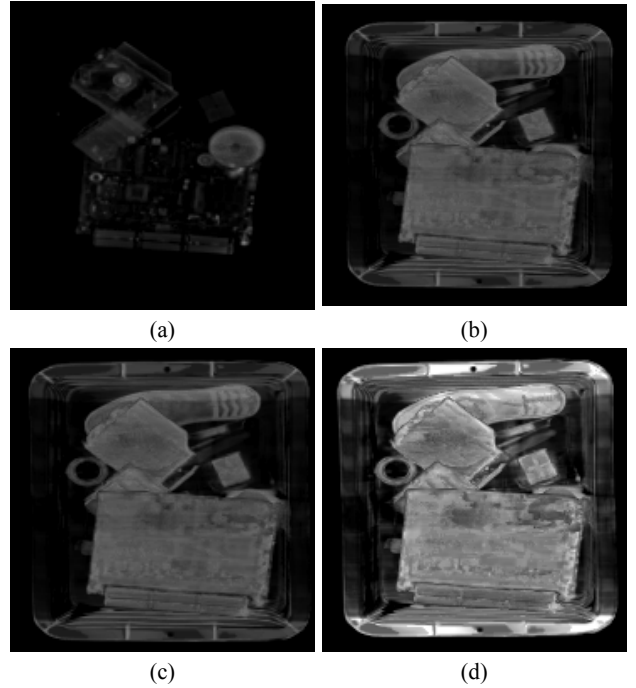


Figure 4. Comparison of the 3D CT baggage image enhancement. (a) Original 3D CT baggage image; (b) Enhanced 3D CT baggage image by histogram equalization; (c) Enhanced 3D CT baggage image by a nonlinear filter; (d) Enhanced 3D CT baggage image by the presented new algorithm.

We first compared the presented new enhancement algorithm with histogram equalization and the nonlinear filtering technique. The comparison results are shown in Figure

4. The original 3D image shown in Figure 4(a) is first applied the image denoising process in Figure 3. It is then directly enhanced by different enhancement methods such as histogram equalization and the Teager filter [13], which is an example of the nonlinear filters. The enhanced results are shown in Figure 4 (b) and (c). Objects are more recognizable than those in the original image. However, some details of the container are very dark and hard to recognize.

The result enhanced by the presented new algorithm is shown in Figure 4(d). The details of objects are more visible than those in the original CT image as well as in the enhanced images in Figure 4(b)-(c). This demonstrates that the presented algorithm outperform the other two enhancement methods.

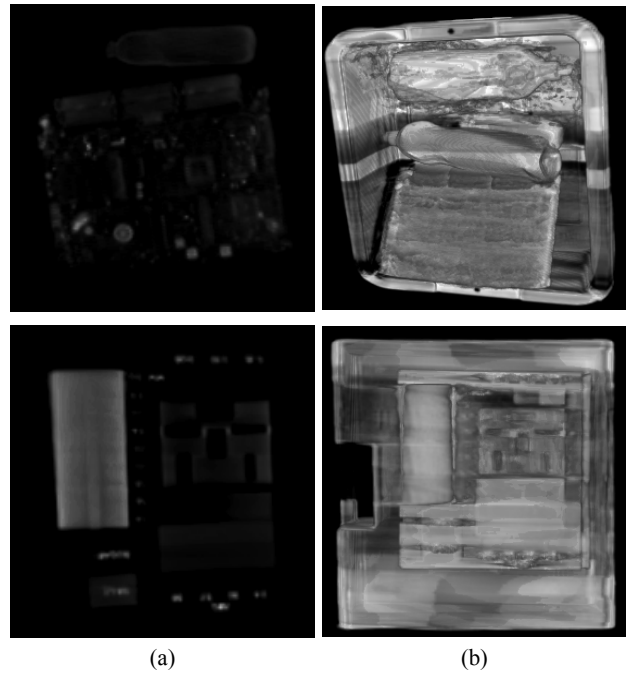
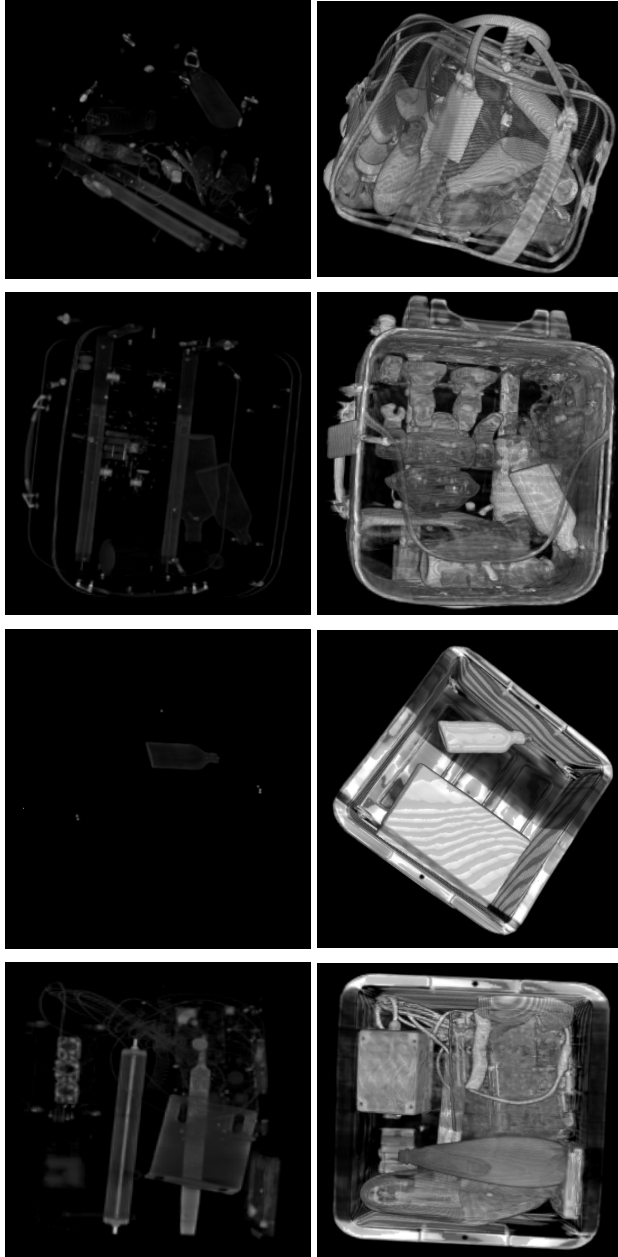


Figure 5. 3D CT baggage image enhancement. The left column shows the original 3D CT baggage images; the right column shows the enhanced results by the presented algorithm. (a) Original 3D CT baggage images; (b) Enhanced 3D CT baggage images. This demonstrates the excellent enhancement performance of the presented new algorithm.

Several other enhanced results are shown in Figure 5. The left column in Figure 5 shows the original 3D CT baggage images while the right column of the Figure 5 gives the corresponding 3D CT baggage images enhanced by the presented new algorithm. The visual quality of the objects and the fine details in the objects is significantly improved. These demonstrate that the presented new algorithm shows excellent enhancement performance.

VI. CONCLUSION

In this paper, we have analyzed the characteristics of the CT baggage images. The images are visually very dark and contain a lot of background projection noise.

To overcome these problems, we have introduced a new 3D CT baggage image enhancement algorithm. The new algorithm is based on the order statistic decomposition.

The new algorithm has been shown excellent performance in enhancing 3D CT baggage images. Experimental results and comparisons have demonstrated that the new algorithm can significantly improve the visual quality of images and fine details of objects while removing the background noise. It outperforms other existing enhancement methods such as histogram equalization and nonlinear filtering.

The new algorithm can be used to enhance the cluttered images with small targets. It has potential applications in object segmentation and recognition for homeland security applications.

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