An Application of Homogeneity Filter to Complete Image Details in 3D Images

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Abstract. In order to complete details in the method of 3D range-gated imaging based on the range-intensity profiles (RIP), we apply homomorphic filtering to tomographic-like serial images in succession. This application filters noise disturbance from low laser illuminating homogeneity, atmospheric scattering and ambient background. First, tomographic-like serial images are filtered by EHPF, BHPF and GHPF, respectively, and three 3D images are reconstructed by RIP correlation algorithm at the same time. And then compare three 3D images under homomorphic filtering and 3D image reconstructed by raw tomographic-like serial images. At last, we analyze and evaluate gray levels in specific regions, which are extracted from tomographic-like serial images and 3D images, correspondingly. The experiments results show that homomorphic filtering is effective in noise elimination and improvement in completing details in 3D images.

Introduction

Three dimensional range-gated imaging based on the RIPs was first proposed to increase imaging speed by Martin Laurenzis et al. of French-German Research Institute of Saint-Louis[1]. Combining the advantages of gated viewing and high-quality rectangular laser to get range-intensity profiles, at least two tomographic-like images are required to obtain a three-dimensional image. This method effectively reduces the amount of pixel data that needs to be processed, and solves the difficulty in traditional "sliced" 3D reconstruction. To fully utilized the intensity information, Zhang et al. of Zhejiang University proposed and an applied exponential code method in 2011, by which the maximum detection depth range increases exponentially with no distance loss[2]. In 2014, Wang et al. proposed a three dimensional super resolution range-gated flash LIDAR based on triangular algorithm of range-intensity correlation[3][4]. Furthermore, they presented a coding method based on triangular algorithm in 2014, and gave an example of seven coding bins of three gate images[5]. The above methods have made a great contribution to the distance accuracy of the three-dimensional imaging based on the original imaging data, but there is not much attention to the detailed information of the three dimensional imaging, such as the edge information, the structural information of the target, etc. The visual effect of 3D reconstruction results is often inferior to that of intensity images. In this paper, the homomorphic filtering algorithm is applied to the noise reduction of two-dimensional slice sequences by means of the triangular distance energy correlation algorithm which is widely practiced at present, so as to reduce the noises caused by laser illumination unevenness, atmospheric scattering, environmental background and sensor error. It is shown that most of fine texture in three-dimensional images is completed, and the visualization effect is also improved.

Three Dimensional Range-gated Imaging Based on RIPs

Acquisition of Tomographic-like Images

Three dimensional range-gated imaging based on the RIPs is different from traditional “sliced” 3D reconstruction. This method taking the advantages of gated viewing and high-quality rectangular laser uses at least two tomographic-like images to obtain a three-dimensional image. The ideal imaging method is as follows.
The laser emits a rectangular laser pulse \( \tau_p \) and triggers the ICCD with a delay time of \( \tau_D \). The gate width is \( \tau_g \). After the radiant energy of laser received from the range gate, we can have a tomographic-like image. Further, by changing \( \tau_D \), a serial tomographic-like images in succession are captured. Figure 1 shows two adjacent time diagrams \((N=1, N=2)\) of range-gated imaging.

![Figure 1. Time diagram of range-gated imaging.](image)

![Figure 2. 3D reconstruction by two sets of RIPs.](image)

**Target Range**

At a distance \( z \) in this range, the range-gate is the convolution of the laser pulse function \( P(t) \) and the ICCD function \( G(t) \) as defined in:

\[
Q(z) = \int_{-\infty}^{\infty} G(t) \cdot P(t - 2 \cdot z / c) dt
\]

(1)

The pixel gray value \( L(z) \) of the two-dimensional slice is positively correlated with the intensity of the echo signal. Therefore, the gray value distribution of the two-dimensional slice can be used to represent the energy \( Q(z) \) of the laser echo signal received from the gate. In order to simplify the calculation, \( I(z) \) is introduced\(^6\). It is neither the expression of any pixel intensity nor an amount of reflected light, but a ratio which expresses how much light can be integrated under particular illumination conditions in comparison with the maximum amount of light can be integrated. And this expression that is called Range-Intensity Profiles (RIP)\(^7\) can be described by:

\[
I(z) = \frac{Q(z)}{\max(Q_i)} = \frac{L(z)}{L}
\]

(2)

\( L \) is the maximum gray value of tomographic-like images (which is 256 in this paper), and the maximum of \( I(z) \) is 1. When \( \tau_p = \tau_g \), the shape of \( I(z) \) is shown in Figure 2. According to Figure 2., we can get that the range information \( z \) does not have a one-to-one correspondence with RIP; a certain range information will not be calculated. So we must use at least two RIPs in succession to reconstruction, and the two RIPs must meet the condition:

\[
\tau_{D,2} - \tau_{D,1} = \tau_p
\]

(3)

\( I(z,1), I(z,2) \) are as shown in Figure 2. Then the target range \( r \) is:

\[
A(r) = I(r,1)/[I(r,1) + I(r,2)], r \in [R_1, R_2]
\]

(4)

\[
B(r) = I(r,2)/[I(r,1) + I(r,2)], r \in [R_1, R_2]
\]

(5)

\[
r = \begin{cases} R_1 + \Delta z_p \cdot B(r) / 2, & r \in [R_1, R_{1,2}] \\ R_2 - \Delta z_p \cdot A(r) / 2, & r \in [R_{1,2}, R_2] \end{cases}
\]

(6)

**Homomorphic Filtering**

In the imaging model of incidence-reflection, an image is the produce of incident component
\(i(x, y)\) and reflected component \(r(x, y)\) as:

\[ f(x, y) = i(x, y) \cdot r(x, y) \quad (7) \]

Normally, in the spatial domain, the incident component changes slowly and the reflected component causes a mutation at the target boundary. It is not easy to filter out the multiplicative noise in the spatial domain. Homomorphic filtering is a filtering method that converts multiplicative noise into additive noise and suppresses noise, which improves the performance of an image by simultaneously compressing the grayscale range and enhancing contrast.

In laser active imaging, the reflection component contains the edge information and structural information of the target existing in the form of high frequency and the smooth region information of the planar target existing in the form of low frequency. The background noise mainly in the form of low frequency in the incident component\(^8\). In order to improve the details and enhance the visualization effect of the three-dimensional image, it is necessary to remove the low-frequency component and retain the high-frequency component, thereby achieving effective separation of the background noise and the target. According to the purpose, a high-pass filter should be designed for noise reduction processing. Considering the particularity of three-dimensional imaging based on RIPS, in order to maintain the original gray level of the image, we choose the traditional homomorphic filtering enhancement method\(^8\). Currently, conventional high-pass filters commonly used in the frequency domain include Gaussian high-pass filters (GHPF), second-order Butterworth-type high-pass filters (BHPF), and exponential high-pass filters (EHPF)\(^9\). The expressions are:

\[
H(u, v) = (\gamma_H - \gamma_L) \left\{ 1 - \exp \left[ -c \cdot D^2 (u,v) / D_0^2 \right] \right\} + \gamma_L \quad (8)
\]

\[
H(u, v) = (\gamma_H - \gamma_L) / \left\{ 1 + \left[ D_0 / D(u,v) \right]^2 \right\} + \gamma_L \quad (9)
\]

\[
H(u, v) = (\gamma_H - \gamma_L) \exp \left\{ -c \cdot \left[ D / D(u,v) \right]^2 \right\} + \gamma_L \quad (10)
\]

This paper introduces homomorphic filtering into three-dimensional imaging based on distance energy to improve the quality of three-dimensional imaging. The flow of the algorithm is shown in Figure 3.

![Figure 3. The description of 3D reconstruction procedure with two 2D images.](image-url)
Experimental Result and Discussion

Quality of Tomographic-like Images

We select a series of tomographic-like images from the imaging experiment of a target with a distance of about $500m^{[10]}$. The width of range-gate and laser pulse are both $100ns$. Time delay is $100ns$ (the condition of Formula (3) in this paper), in other words, effective range distance is $15m$. The original slice images are shown in Figure 4(a) (b). The first images that are filtered by GHPF, BHPF and EHPF in the series are showed in Figure 4(c)(d)(e). Parameters in high-pass filters are selected in order to effectively enhance images.

![Original slice 1](image1)  ![Original slice 2](image2)  ![Slice 2 after GHPF](image3)  ![Slice 2 after BHPF](image4)  ![Slice 2 after EHPF](image5)

Figure 4. Raw gate images and gate images after GHPF.

The Pearson correlation coefficient $(SROCC)$ can be used to reflect the linear correlation between the two variables. In this paper, we use $SROCC$ to evaluate the imaging quality after three types of high-pass filtering. According to Formula 6, the correlation between $A(r)$ and $B(r)$ will directly affect the calculation of range information $^{[11]}$. We selected the 270th column of the images from 70th row to 512th row (this part is mainly the surface of the wall, so that the reflectivity could be regarded as equal), and the 150th column of the images from 100th row to 400th row (this part contains glass, metal and wall, so that the reflectives are different) as the target areas to be calculated. The specific positions are as shown in Figure 4(a). The $SROCC$ of original images and images filtered by GHPF, BHPF and EHPF are listed in Table 1.

![Table 1](image6)

<table>
<thead>
<tr>
<th></th>
<th>Column 150 (CD)</th>
<th>Column 270 (AB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw images</td>
<td>0.8413</td>
<td>0.8464</td>
</tr>
<tr>
<td>After BHPF</td>
<td>0.8908</td>
<td>0.8489</td>
</tr>
<tr>
<td>After EHPF</td>
<td>0.8874</td>
<td>0.8506</td>
</tr>
<tr>
<td>After GHPF</td>
<td>0.7666</td>
<td>0.9131</td>
</tr>
</tbody>
</table>

During the imaging process, the noise caused by atmospheric turbulence, background noise and sensor error is random, therefore noise damages correlations. The linear correlation degree of the filtered three groups of images is slightly higher than that of the original image. This result verifies that the homomorphic filtering can effectively separate the noise.

Range Precision

The original images and three groups of images after homomorphic filtering are reconstructed. The results are shown in Figure 5. As the effective range information is $15m$, the reconstructed range information of original series is compressed to about $8m$. The reconstructed range information of filtering series is about $11m$ and range resolution is less than $1m$.

By comparing the intensity images, the details of the three-dimensional reconstructed image after homomorphic filtering are more obvious. For example, due to insufficient laser irradiation at the corner of the roof of the upper left building, this part of the information is not recovered when the original image is reconstructed. Homomorphic filtering eliminates the limited influence of the laser irradiation area, so that the upper left information is recovered. The reconstruction result after GHPF is better. Also, windows area of the building has different materials (resulting in uneven reflectivity), small area and small spacing. The details of the windows area are extremely blurred during the reconstruction of the original picture, and the visualization effect is poor. After
homomorphic filtering, the details of the window area are basically reconstructed, and the reconstruction result of BHPF is better. From the overall situation, the uniformity of the filtered image decreases, and a large number of obvious invalid points appear.

![Figure 5. Reconstruction results with depth map.](image)

The area AB and CD in three-dimensional reconstruction data in original image and images after the homomorphic filterings are compared to evaluate imaging effects of various methods. The gray value of the corresponding region is extracted and represented in the form of scatter plots, as shown in Fig. 6 (a) and (c). For the area AB, the main component of the target is the wall, and the distance information is stable, so a linear fit is used, and the fitting result is shown in Fig. 6(b). For the regional CD, the target component is more complicated, and the distance information is less stable. Therefore, the high-order polynomial fitting is used, and the fitting result is shown in Fig. 6(d). It can be seen that the results of the homomorphic filtering are consistent with the trend of the grayscale information of the original images. For areas with a simple structure, homomorphic filtering can enhance the image visualization effect while ensuring the original image information. However, for a more complex structure, the noise reduction effect of homomorphic filtering leads to the expansion of the local structure, which causes errors. Such errors decrease the uniformity of the reconstructed image after filtering.

![Figure 6. Gray value distribution and corresponding Fitting result.](image)
Summary

Three-dimensional imaging based on RIPs requires less data than traditional “sliced” three-dimensional imaging, and has great advantages in three-dimensional imaging of targets with long range information. In this paper, the homomorphic filtering is applied to the filtering and noise reduction process of the two-dimensional slice sequence. By applying to the actual image processing, it is verified that the homomorphic filter can effectively reduce the laser illumination without guaranteeing a certain distance accuracy, reduce uniform, atmospheric scattering and noise caused by background stray light, and effectively improve the detailed information of three-dimensional reconstructed images. This application provides a direction to effectively identify the type of target for the human eyes and to eliminate the effects of uneven reflectance of the target. At the same time, the uniformity of the reconstructed three-dimensional image after homomorphic filtering is nonuniform, and there are a large number of invalid points. Further research will carry out to homogenize the three-dimensional image and to design algorithms for enhancing three-dimensional images while ensuring distance accuracy.

References


