Three-dimensional imaging through scattering media by constructing a digital twin based on Gaussian Splatting

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Introduction

Imaging through scattering media is an important technique in various fields including bioimaging. In recent years, optical and computational approaches have developed the field of scattering imaging. However, while many of these methods focus on the two-dimensional shape of the object, achieving three-dimensional (3D) imaging continues to be a challenging task. A digital twin, which is a digital model constructed by data assimilation, emulates a complicated shape and a behavior of a physical object in virtual space. The construction of the digital twin and its interaction with a physical process enable the imaging of complex objects which would be difficult to observe in real space. We aim to achieve accurate 3D imaging through scattering media by using the digital twin. In this study, we attempt to construct a 3D digital twin based on Gaussian Splatting [1]. Gaussian Splatting is a method for representing 3D scenes using ellipsoids with opacities following a 3D Gaussian distribution. By introducing a scattering or de-scattering process into the native algorithm, which is proposed in Ref. [1], an object behind a scattering media can be reconstructed. We investigated a 3D model for a blurred object constructed by the proposed method.

Method

Figure 1 shows a procedure of the proposed Gaussian Splatting with scattering process. A set of images captured from multiple viewpoints is input to Structure-from-Motion (SfM) [2], which produces a point cloud and estimates a set of camera poses, which are positions and orientations of cameras. The initial point cloud is converted to a set of 3D Gaussians with opacities following a Gaussian distribution by adding three parameters: (a) 3D covariance matrix Σ, (b) opacity α, and (c) spherical harmonic coefficient c which represents the color. For rendering, the 3D covariance matrix is transformed to a 2D covariance matrix Σ^{2D} in the coordinates determined by the camera poses estimated by SfM. Each pixel value in rendered images is formulated as the alpha-blending of N ordered points that overlap the pixel: $C_{\mathrm{pix}} = \sum_i^N c_i \alpha_i^{2D} \prod_j^{i-1}\left(1-\alpha_j^{2D}\right)$, where α_i^{2D} represents the i-th Gaussian's opacity weighted by the 2D Gaussian covariance Σ^{2D}. In this study, the scattering process produces scattering images (I_{scat}) from the rendered images (I_{GS}) with the pixel value C_{pix} as follows:

$$I_{\mathrm{scat}} = \mathrm{PSF} * I_{\mathrm{GS}}, \tag{1}$$

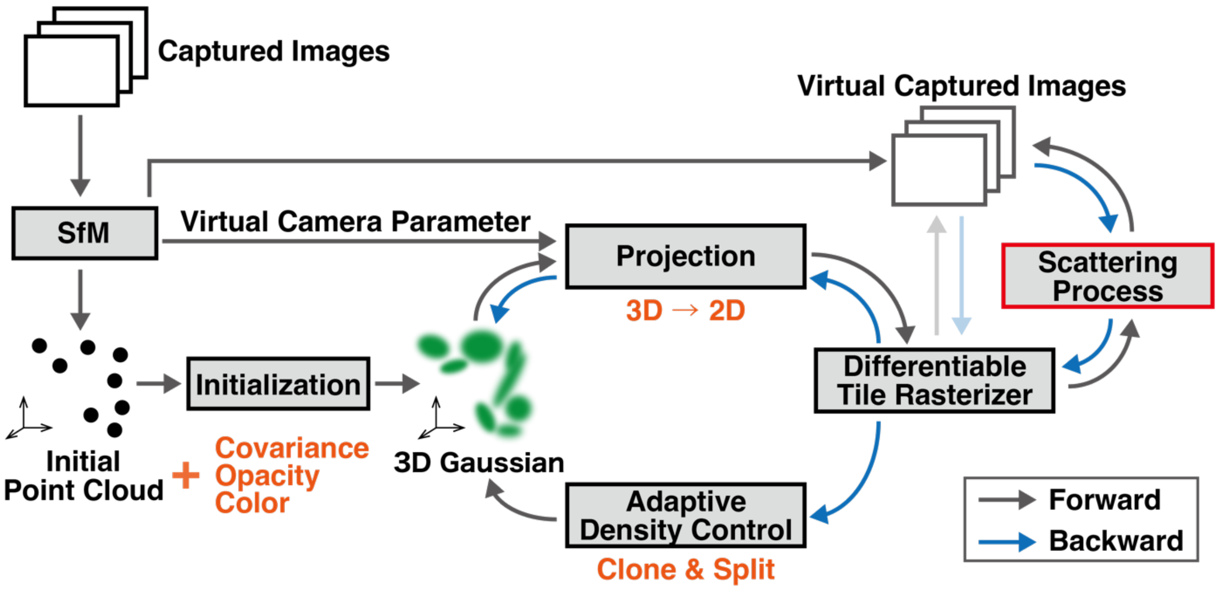

Fig. 1 A procedure of the proposed algorithm with scattering process.

where ∗ denotes the convolution and PSF is a point spread function. Image degradation such as blurring and scattering is modeled by the convolution with a PSF [3]. By introducing this process, the effects of scattering cam be removed. The 3D Gaussian parameters (position, covariance, opacity, color) are optimized by stochastic gradient descent techniques using a loss function based on the L1 norm and the D-SSIM term with the captured images and scattering images. In addition, the number of Gaussians and their density over unit volume is controlled adaptively by cloning and splitting it in two. A de-scattered 3D models can be constructed by iterating this procedure.

Experiment

To verify the de-scattering capability of the proposed method, a set of blurred images was input to the native and proposed algorithm. As the blurred images, we used a set of images created by convolving a PSF on the images of the target object captured from multiple viewpoints. The PSF was represented by a Gaussian distribution with standard deviation of 5 pixels, and the same PSF was used in equation (1). Figures 2(a)-(c) show the image of the object from a viewpoint, and the reconstructed images by native and proposed algorithm. While native Gaussian Splatting remained a blurred image, the proposed method reconstructed the object without blur. To evaluate the contrast, the width of the white line on the object was measured along the blue horizontal line in the enlarged images. Figure 2(d) shows the widths in each image from all viewpoints. The concordance ratio between the widths of the captured and reconstructed images is 26.3% for the proposed method, compared to 3.95% for the native method. We demonstrated that the proposed method could construct a 3D model with high contrast.

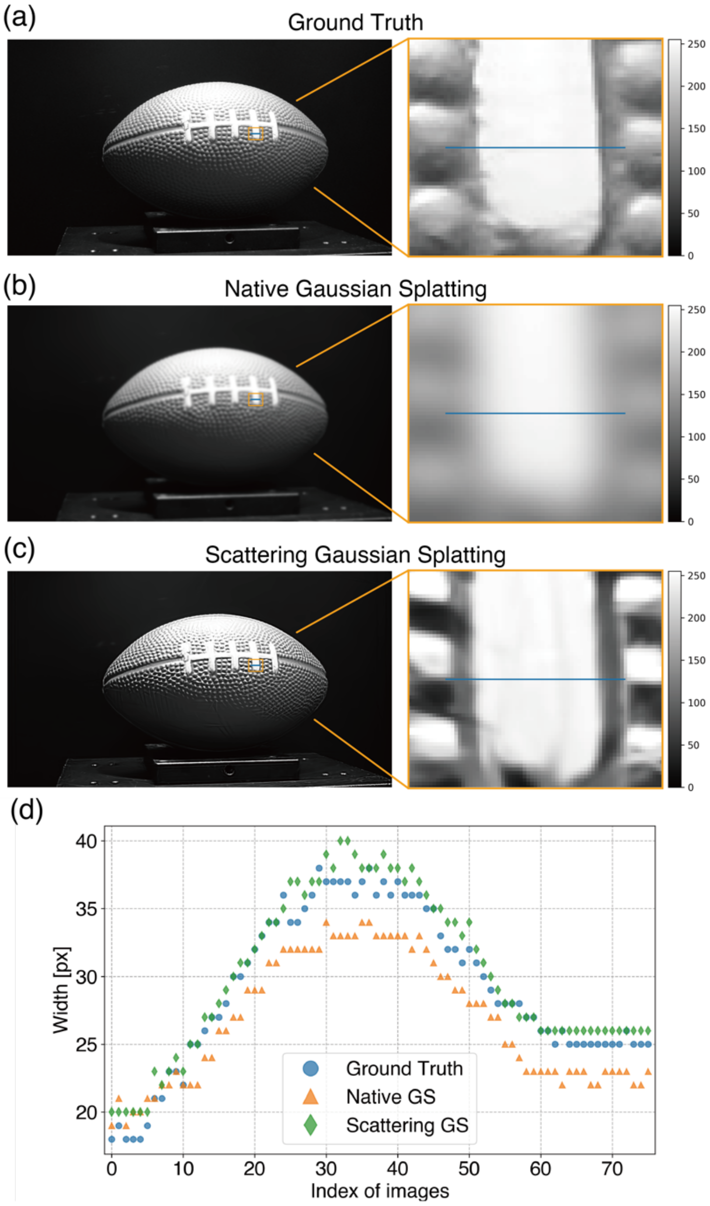

Fig. 2 Reconstruction results. A captured image from a viewpoint (a) and reconstructed images by native (b) and scattering Gaussian Splatting (c), and partial enlarged images of them. (d) The distribution of widths of the white line on the object in the images from all viewpoints.

Conclusion

This study shows that 3D object can be reconstructed from the blurred images by introducing the convolution and deconvolution of the PSF. Future work includes the construction of 3D models for objects behind the actual scattering media.

Acknowledge

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