Smoothing Range Image using Reflectivity

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***Abstract*— This paper proposes a new smoothing technique for range images taken by a Time-of-Flight range finder. The most of Time-of-Flight range finders measure not only the range data but also the power of the reflected light as a side product. The basic idea of the propose technique is that the reflectance and range images are utilized for smoothing the range image corrupted by noise so that the detailed shape in the range image is preserved.**

I. Introduction

In recent years, a variety of low cost and real time Time-of-Flight (RT-TOF) range scanners have been commercially available. On the other hand, high-precision (but very expensive) three dimensional laser range finders have been developed for landscape surveying or digital 3D modeling. We also have been developing a low cost and high resolution laser measurement systems using a laser scanner and a rotary table for 3D environmental map building[1]. However, range images acquired by these sensors are suffered by small noises due to the reflectance property of objects' surfaces or electrical and mechanical errors. Therefore the denoising problem for range sensors (RT-TOF range scanners and LIDAR sensors) still remains as an essential problem.

In this paper, we propose a new smoothing technique focusing on the reflectivity. This method allows us to smooth a range image and remove noises while preserving detailed shapes.

II. Smooothing using Reflectivity

A. Reflectance Image

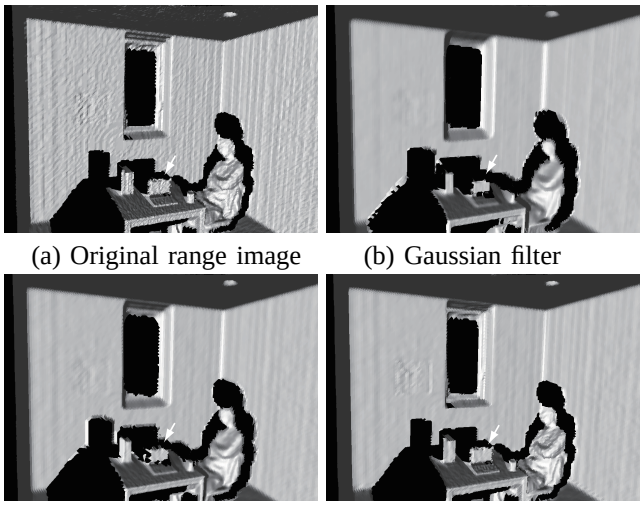
Optical range sensors such as a laser range finder obtain range data by measuring a round-trip time of a laser pulse reflected by an object. On the other hand, most of optical range sensors can measure the intensity of the reflected laser pulse (reflectivity) with its round-trip time. The intensity value is determined uniquely according to the pixels in the range image. In other word, the range image and the reflectance image are fundamentally aligned precisely. Therefore, we will use not only the range image but also the reflectance image for smoothing the range image.

B. Edge-preserving Smoothing filter

We propose a new edge-preserving smoothing filter which utilizes reflectance and range images for smoothing a range image as follows:

$$g_i = \frac{\sum_j w(x_i, x_j) w(f_i, f_j) w(d_i, d_j) f_i}{\sum_j w(x_i, x_j) w(f_i, f_j) w(d_i, d_j)} \tag{1}$$

$$w(x, y) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{|x-y|^2}{2\sigma^2}} \tag{2}$$



(a) Original range image (b) Gaussian filter

(c) Bilateral filter (d) Proposed filter

Fig. 1. Experimental results for a complex environment

Where f_i and d_i are the range and reflectance value in pixel x_i, and $w(x_i, x_j)$, $w(f_i, f_j)$, and $w(d_i, d_j)$ are Gaussian functions in the spatial, range, and reflectance domains with standard variations of σ_x, σ_f, and σ_d, respectively.

III. EXPERIMENT

We applied the proposed method to the data acquired by CPS-V[1]. Figure 1(a) shows original data, and the results of denoising by Gaussian filter, Bilateral filter and the proposed edge-preserving smoothing filter are also shown in Figure 1(b), (c) and (d). Gaussian and Bilateral filter enable to smooth the surface of walls, and especially Bilateral filter can preserve the shape of a monitor (the arrow). However, the roof edges of walls, the face of a person, and the wrinkles of the clothes are also becoming dull. On the other hand, we can say that proposed edge-preserving smoothing filter smoothes the range image successfully while preserving the jump and roof edges appropriately.

IV. CONCLUSION

This paper proposed the new edge-preserving smoothing filter for range images using reflectance values acquired as the by-product of the range value with Time-of-Flight sensors.

References

[1] Ryo Kurazume, Yusuke Noda, Yukihiro Tobata, Kai Lingemann, Yumi Iwashita, and Tsutomu Hasegawa, Laser-based Geometric Modeling using Cooperative Multiple Mobile Robots, in Proc. IEEE International Conference on Robotics and Automation, pp.3200-3205, May 12-17, 2009.