TIME-OF-FLIGHT IMAGING OF INDOOR SCENES WITH SCATTERING COMPENSATION

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Extended abstract:

TOF cameras rely on active illumination and measure range from the time needed for light to travel from the camera light source to the scene and back to the camera. Recent time-of-flight (TOF) cameras allow for real-time acquisition of range maps. For instance, the Swissranger SR-3000 camera has a 176x144 sensor, and supports continuous operation at 20 Hz [1]. The depth resolution can be higher than 1 cm in favourable conditions: indoors, with no bright light sources in the field of view [2].

However, depth measurement can be degraded by secondary reflections occurring between the lens and the imager. This phenomenon is designated thereafter as scattering [3]. Range image degradation by scattering occurs mainly when the spread of depth imaged is wide. In that case, the signal from far objects (background) can be affected by scattering from foreground objects. Figure 1 shows intensity images of a typical situation where range image degradation by scattering occurs. The background is an empty room, and the foreground object is a person standing in this room. Figure 2, (a) and (b), shows the corresponding depth maps.

The problem of scattering compensation by image processing methods is first discussed. By using a formalism where the data acquired by the TOF camera is expressed as a two-dimensional complex signal, scattering can be modelled as a convolution operation on this signal. In that case, scattering compensation can be realized by applying an inverse filter on the 2D complex signal returned by the camera [4]. We will show that, due to the anisotropic nature of the scattering phenomenon, the degradation is more pronounced along sensor rows than along sensor columns, and the filter employed must be wide. For good scattering compensation results, the width of the inverse filter can be as large as 160 pixels.

In this paper, we also discuss the suitability of the inverse filter approach for real-time operation. Straightforward two-dimensional filtering is prohibitively expensive, due to the large filter size. However, by restricting the expression of the inverse filter to a sum of separable gaussians, real-time performance can be attained. Moreover, using separable gaussians allows to account for the anisotropic behaviour of scattering, by using different standard deviations along sensor rows or columns.

We emphasize that the processing time can be reduced by a factor close to 100 when using the separable sum of gaussians expression. With this type of filter, scattering reduction is

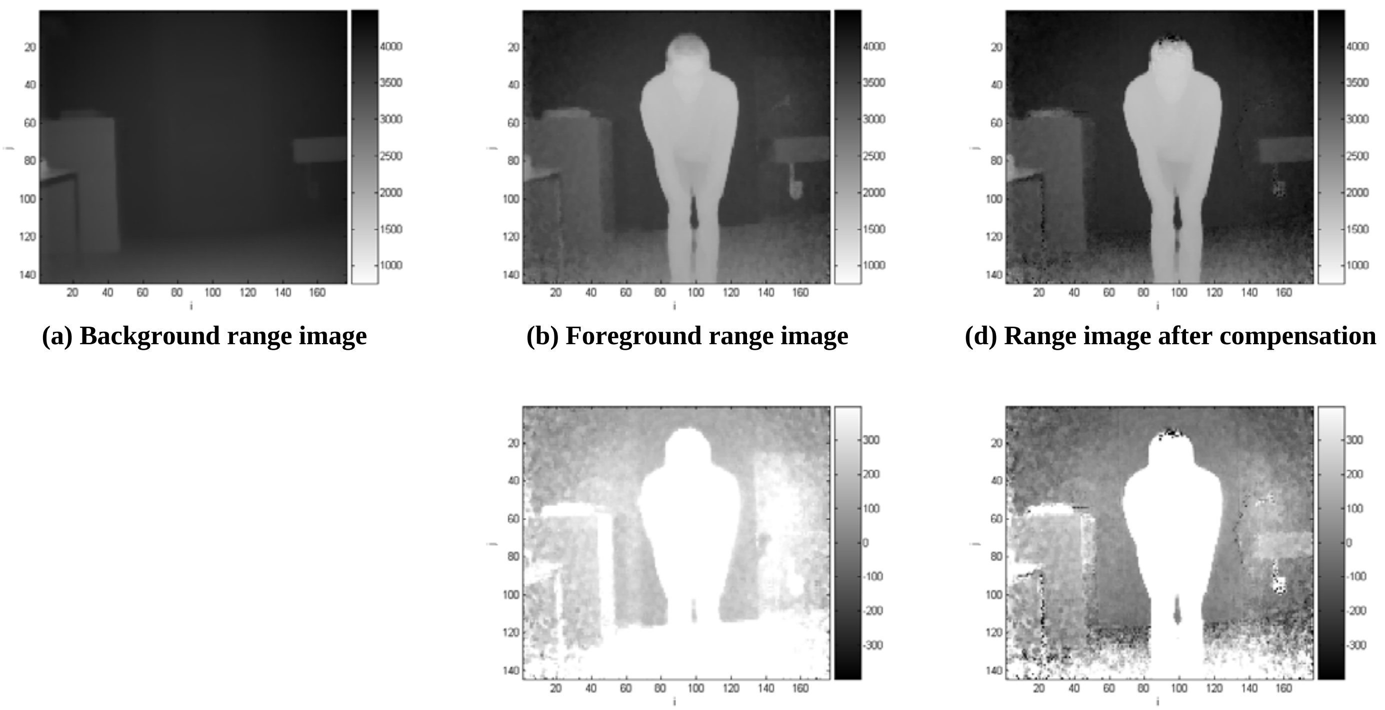
performed in less than 460 ms per frame, on a single core, 3.2GHz Pentium 4 processor, for a filter of width 160 pixels.

The performance can be increased further by using optimized filtering functions available in commercial image processing libraries. For the same filter, the processing time is reduced to 85ms when using Intel IPL 2.5. This implementation allows continuous operation at 10 Hz, which is high enough for many real-time range imaging applications. A typical result of the scattering compensation process is illustrated in fig. 2(d).

Finally, we will briefly outline our strategy to reach 20Hz continuous operation. Since the processing time scales with the filter size, we are currently investigating inverse filter optimization, aiming for better scattering compensation, but also for lower filter size.

(a) Background scene **(b) Foreground scene**

Figure 1 : Intensity images of a typical indoor scene where TOF range imaging is affected by scattering.



(a) Background range image **(b) Foreground range image** **(d) Range image after compensation**

(c) Range difference **(e) Range diff. after compensation**

Figure 2 : Illustration of scattering compensation scattering and scattering compensation. The scale is given in mm.

References:

[1] MESA.: Swissranger SR-3000 manual v1.02, Jul 2006. http://www.swissranger.ch

[2] Kahlmann *et al.*: Calibration for Increased Accuracy of the Range Imaging Camera SwissRangerTM, *Proceedings of the ISPRS Com. V Symposium*, Sep 2006

[3] Santrac *et al*.: High Resolution Segmentation with a Time-of-flight 3D Camera using the Example of a Lecture Scene, Technical report, Sep 2006 http://www.inf.fu-berlin.de/inst/ag-ki/eng/index.html

[4] Puetter *et al*.: Digital Image Reconstruction: Deblurring and denoising, *Annual Review of Astronomy and Astrophysics*, 43:139:194, Sep 2005..