Time-of-Flight 카메라 영상 보정

Enhancement on Time-of-Flight Camera Images

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Abstract Time-of-flight(ToF) cameras deliver intensity data as well as range information of the objects of the scene. However, systematic problems during the acquisition lead to distorted values in both distance and amplitude. In this paper we propose a method to acquire reliable distance information over the entire scene correcting each information based on the other data. The amplitude image is enhanced based on the depth values and this leads depth correction especially for far pixels.

Key words: range camera, Time-of-Flight camera, image filter

1. Introduction

Natural and effective Human-Computer Interaction (HCI) is increasingly getting important due to the prevalence of computers in human activities. Because of the fact that cameras provide non-intruding user interface, computer vision continues to play an important role in the HCI realm such as gesture recognition. However, computer vision methods often fail to become pervasive in the field due to the lack of real-time and robust algorithms. Especially, when acquiring range data, the methods based on triangulation or interferometry are computationally expensive and not real time capable.

A rather new kind of device called Time-of-Flight(ToF) 3D camera, promises real-time range sensing . We use a miniature camera called "SwissRanger-3000" built by CSEM, which uses its own illumination system with modulated infrared light and measures the diffused light reflected back by the objects in the scene. The output of the camera consists of a depth image and a conventional low resolution gray-scale amplitude image [1,2].

However, data acquired from the camera have significant amount of noise due to the systematic issues which should be removed for stable usability. Breuer et al. applies a simple median filter to the range image to reduce speckle noise [3]. Oprisescu et al. corrects the information based on the two inputs amplitude and range [4]. However, it requires pre-experiment for tuning the parameters.

In order to reduce the high level of scattering noise from the ToF camera images, we apply bilateral filter which smooths amplitude and depth data while preserving the edges. The main amplitude-related error comes from the fact that power of wave decreases by distance. Thus, for objects with same reflectance, the one located far in distance has low amplitude results. The noise in the depth image can be

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reduced if the amplitude values at the same position are low due to the distance.

2. Bilateral Filtering

The amplitude and depth information provided by the ToF camera has an considerable amount of noise, therefore we need to apply a filter for each image to reduce the noise. Bilateral filtering is a non-linear single pass filter which preserves the image features [5]. The two contradictory goals are achieved by applying two Gaussian filters at a localized pixel neighborhood, one in the spatial domain, named domain filter, and one in the intensity domain, named range filter. For the depth image we use the depth domain for the range filter.

Let f :R→R be the original image. Then for any given pixel a at (x,y) within a neighborhood of size n, which has a_0 as its center, its coefficient assigned by the range filter $r(a_0)$ is determined by the following function:

$$r(a_i)=e^{\frac{[f(a_i)-f(a_0)]^2}{2\sigma_r^2}} \tag{1}$$

Similarly, its coefficient assigned by the domain filter g(a) is determined by the proximity function below:

$$g(x,y;t)=e^{\frac{x^2+y^2}{2t}} \tag{2}$$

where t is the scale parameter.

For the central pixel of the neighborhood a_0, its new value is denoted by $h(a_0)$

$$h(a_0)=k^{-1}\sum_{i=0}^{n-1} f(a_i)\cdot g(a_i)\cdot r(a_i) \tag{3}$$

where k is the normalization constant to maintain zero-gain and is defined as the following function:

$$k=\sum_{i=0}^{n-1} g(a_i)\cdot r(a_i) \tag{4}$$

Figure 1 shows the original depth image and the out filtered output image applying bilateral filter.

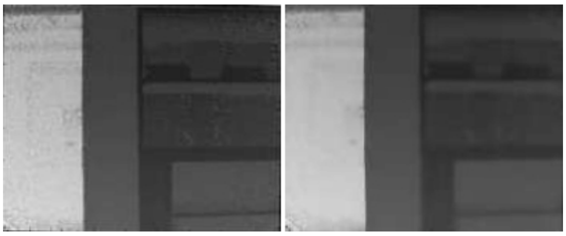

Fig 1. Bilateral filtering on depth images. Original depth image (left). Filtered image with t=2, σ_r^2=0.1 (right).

3. Amplitude Correction with Depth

The amplitude image given by a ToF camera has the drawback that objects located at a far distance appear darker than those located near the camera, even for objects with the same reflectance. The contrast of an image acquired by a ToF camera and an image from a common webcam are shown in Figure 2. One can notice that the intensity of the wall on the left side appears darker in the ToF image rather than that from the webcam image. This is mainly due to the fact of having a infrared lighting fixed at the ToF camera whereas the scene lighting is even for the webcam.

Fig 2. A typical amplitude image delivered by a ToF camera (left), same scene viewed by a webcam (right).

As intensity of an object decreases proportionally to the square of distance to the object [6], we can modify the amplitude of each pixel by multiplying the amplitude with the square of the distance obtained from the ToF camera as

$$f'(a_i)=f(a_i)d^2(a_i) \tag{5}$$

where $f(a_i)$ represents the original amplitude value and $f'(a_i)$ represents the corrected amplitude value of a pixel. Additionally, the signal decreases radially from the center to the corners, which result to small values. It appears in left image of Figure 3 that dark pixels increase toward the corners. Therefore, we magnify each pixel $f'(a_i)$ by the exponential of its normalized distance to the center of the image, as shown in Eq. 6. Through this correction the amplitude looks more even over the entire image as shown in the right image of Figure 3.

$$f''(a_i) = f(a_i)d^2(a_i) \cdot e^{dist(a_i - a_0)} \qquad (6)$$

Fig 3. Distance-based correction amplitude image with Eq. 5 (left), with Eq. 6 (right).

Owing to the fact that the depth image is affected by noise, the square value of inaccurate values could lead to enhancement of noise. However, in the following section, we filter the depth image without weighting the exact values of the enhanced amplitude image to prevent the scattering values influencing the depth image.

4. Distance Correction Based on Amplitude

In the depth image, noise appears more frequently when the distance to an object increases. In such areas the amplitude is usually of low values. We could exclude outstanding depth values in far distance by comparing them to the amplitude image. In brief, if two neighbored pixels in the depth image have large difference whereas in the amplitude image the difference is small with low values, we can consider it as a far region and the depth value as biased. Consequently, we are able to correct this depth value. However, we have to distinguish if the amplitude has low value because of long distance or low reflectance due to a dark object. These two cases can be held apart by using the original and the enhanced amplitude images produced in Section 3.

4.1 Amplitude Difference Map

In order to extract low amplitude based on far objects we take advantage of the original amplitude image $f'(a_i)$ and the enhanced amplitude image $f''(a_i)$in Section 3. We create an amplitude difference map $ADM(a_i)$ by calculating for each pixel the difference of the two images $ADM(a_i) = f(a_i) - f''(a_i)$. Large $ADM(a_i)$ value would state that these pixels were corrected by the depth image beforehand and consequently can be considered as far object. This means high reflectance objects appeared dark in the image - having low amplitude value - caused by far distance. The large values in $ADM(a_i)$ map appear with bright intensity in Figure 4.

Fig 4. Amplitude Difference Map. As the value gets larger, corrected by longer distance, it has bright intensity.

4.2 Compare Depth Image and Amplitude Difference Map

Now we have to find noise pixels in the depth image. We apply an n x n moving window to compute the standard deviation of the depth values. We assume that n is small so that the area does not fluctuate heavily within the window kernel. The bigger the standard deviation is, the more difference between neighboring pixels. Generally, there are two reasons that cause the big difference. One is edge feature and the other is noise. If the depth difference is bigger than a threshold d at $d'(a_i)$ and the value at the amplitude difference map $ADM(a_i)$ is bigger than threshold e, we assume that the pixel $d'(a_i)$ has noise and apply a simple median filter. The problem here is that tuning the thresholds d and e is not trivial. In the end, defining d is not essential to the output result. Furthermore, the standard deviation of the depth values were normalized in order to apply by percentage. Figure 5 shows the result of this procedure. For further approaches, if the ADM map is accurate, then we could filter the $d'(a_i)$ weighted with the ADM rather than just by a median filter.

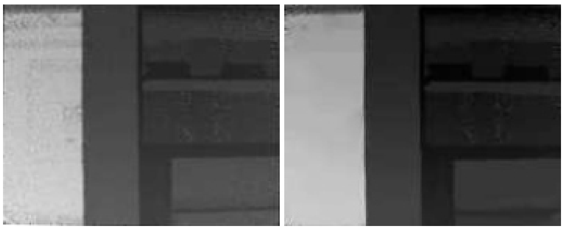

Fig 5. Origin depth image (left). Amplitude-based correction on depth image with amplitude difference map (right).

In Figure 6 we present the 3D surface of the depth image throughout the procedure.

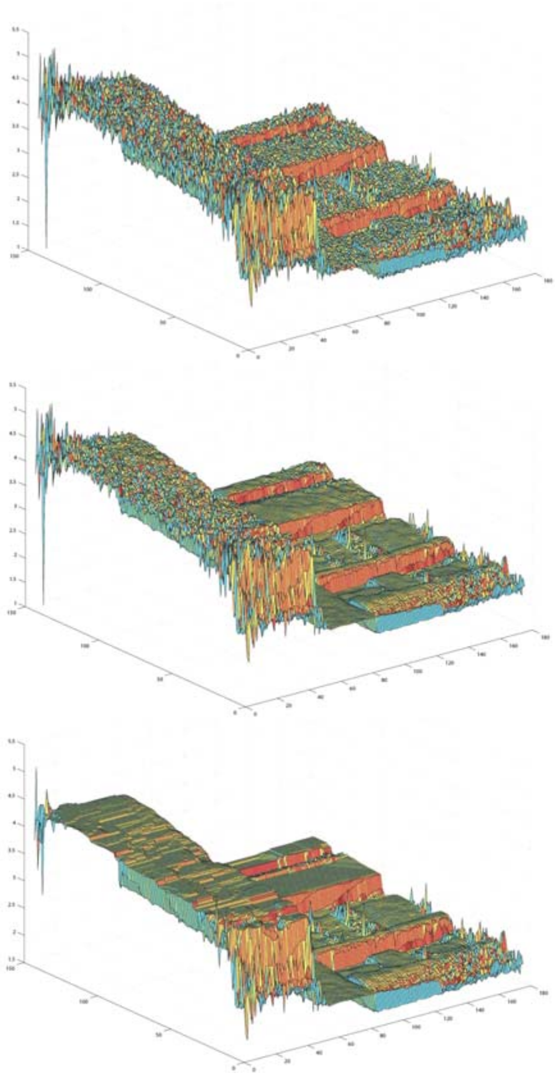

Fig 6. The original depth image (top). The depth image after bilateral filter (middle). Final depth image after the amplitude-based filter (bottom).

Even if the correction is not perfect, one may notice that the surfaces are less noise prone. And the difference of the original depth image and the enhanced depth images are shown in Figure 7.

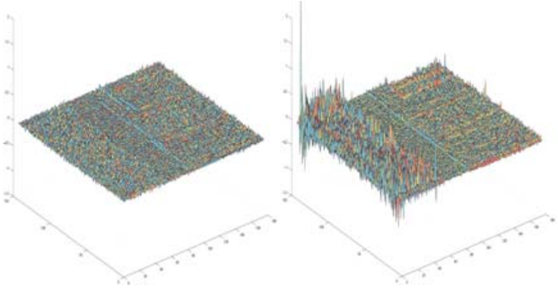

Fig 7. Difference of original depth image and the image processed with bilateral filter (left). Difference of the original depth image and the image processed with amplitude-based filter (right). Our method excludes more noise than existing filters.

6. Conclusion

In this paper we have presented methods to correct the images acquired from the Time-of-Flight camera. First, we filter the images separately and then correct the images using the correlated facts. For further research, we have to consider dark objects located in near distance. Moreover, by extending the bilateral filter considering the amplitude difference value, we could reduce the step of processing and filtering and approach to the real-time condition. The noise seems to be only dependent on the amplitude and not on the depth. Therefore our algorithm could still be simplified on future work.

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