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Extended Abstract of Ph.D Thesis
Noise modeling and depth calibration for Time-Of-Flight cameras

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1 Abstract

3D cameras open new perspectives in different application fields such as 3D reconstruction, Augmented Reality and video-surveillance since they provide depth information at high frame-rates. However, they have limitations that affect the accuracy of their measures. In particular for TOF (Time-Of-Flight) cameras, two types of error can be distinguished : stochastic noise of the camera and the depth distortion. This is illustrated in the figure 1 where a depth image of a cube is presented. The pixel (x, y) is the depth measure of the 3D point $\mathbf{Q}$. This depth measure (d_{TOF}) is compared to the real depth d_{GT}. d_{TOF} corresponds to a distorted measure of d_{GT} in addition to the stochastic noise.

In state of the art of TOF cameras, the noise is not well studied and the depth distortion models are difficult to use and don't guarantee the accuracy required for some applications. The objective of this thesis is to study, to model and to propose an accurate and easy to set up calibration method of these two errors of TOF cameras. For both stochastic noise and depth distortion of TOF cameras, two solutions are proposed. Each of them

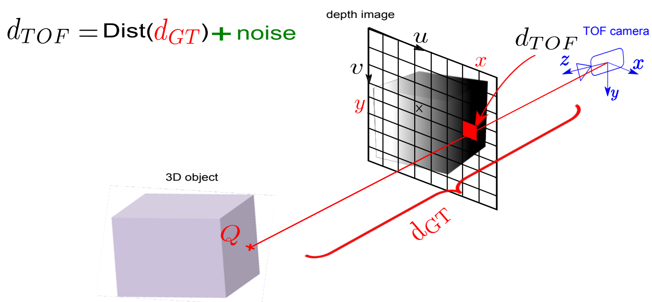

Figure 1: The depth measured by the TOF camera (d_{TOF}) corresponds to a distorted measure of d_{GT} (real depth) in addition to the camera noise.

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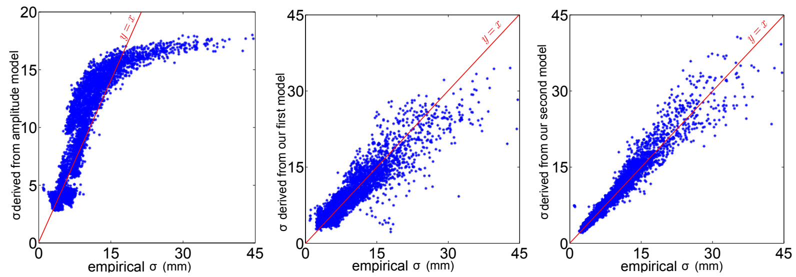
gives a solution for a different problem. The former aims to obtain an accurate model. The latter, focus on the simplicity of the set up.

Thereby, for the camera noise, while the majority of the proposed models are only based on the amplitude information, we propose a first model which integrate, in addition, the pixel position in the image. To improve the accuracy, we propose a second model where the amplitude is replaced by the depth and the integration time [3]. The proposed models use a 3D smoothing spline, known as a 3D Thin-Plate Spline, known to work well to model complex variations. An evaluation of our models is shown in figure 2 : σ derived from noise model is plotted against σ derived empirically. It shows that our models outperform those based only on the amplitude.

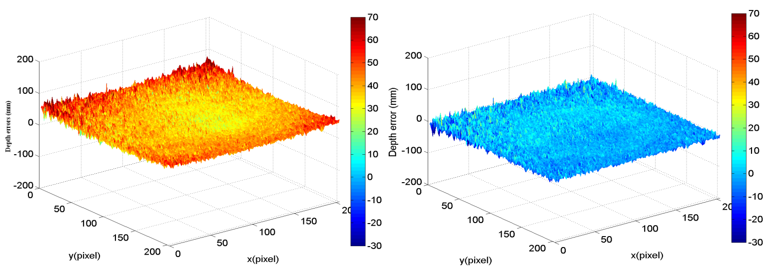


(a) model based amplitude (b) our first model (c) our second model

Figure 2: Comparison between noise models. For a perfect model, the points must go through the line $y = x$.

Regarding the depth distortion, a first solution based on a non-parametric model, contrary to most of the other methods, is proposed [4]. It models under the same formalism the distortion variation according to the distortion factors (the distance and the pixel position in the image). This guarantee a better accuracy even at the image boundaries which are typically more distorted than the image center. An example comparing the depth error before and after the depth correction is shown in figure 3. Then, a second solution based on the prior knowledge about the planar geometry of the observed scene is presented [2]. It is based on a non-planarity correction that needs depth measurements of different plan views and an affinity correction that requires a very small set of ground truth measurements, contrary to state of the art approaches. Thus, it is more easy to use, compared to the methods of the literature, and does not need a large set of accurate ground truth that is extremely difficult to obtain in practice. An evaluation on a fronto-parallel view is shown is the figure 4. After the non-planarity correction (NPC), a perfect plane is obtained (figure 4c): however, it is not aligned with the ground truth. It is shown in the figure 4d that after the affinity correction (AC) the final corrected plane is very close to the ground truth.

Finally, an applicative example that shows the use of our models on real data is presented. In fact, the depth distortion model and the noise model are combined to increase the accuracy associated to TOF measurements and describe their quality by providing the uncertainty associated.



(a) (b)

Figure 3: Depth error before (a) and after (b) depth correction.

The various contributions described above are implemented, tested and compared to the state of the art on real data. The obtained results are detailed in my PhD thesis [1].

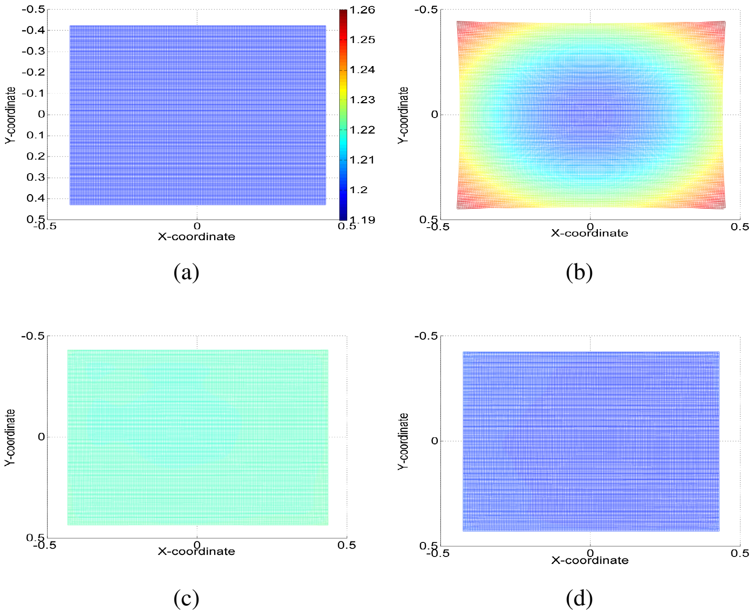


Figure 4: A view of the plane (a) undistorted (b) before correction, (c) after NPC and (d) after AC.

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