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Standardization of Intensity-Values Acquired by Time-of-Flight-Cameras

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Motivation

Amplitude images from ToF-cameras provide valuable information about the scene [2], but they are biased in several ways [3]:

- Different integration times lead to completely different value ranges.
- Attenuation of the intensity depending on the distance to the object.
- Due to uncommon reflection properties specular reflections can occur.
- Inhomogeneous illumination of the scene leads to dark image borders.

➥ These effects make it impossible to find integration time and distance independent parameters for various image processing steps like segmentation, classification, threshold computation etc.
➥ The aim of this work is to find rescaling methods which lead to **intensity images that have a common value range, independent from the integration time and distance** between object and camera. All results were obtained using a CSEM Swissranger SR-3100 [1].

Integration Time Bias

Ideal amplitude gain depending on integration time:

$$A_{final} = A_{spec}c \qquad (1)$$

- A_{final} : actual acquired amplitude value.
- A_{spec} : amplitude value for a specific integration time.
- c : multiplier for current integration time.

Saturation effects on the camera chip lead to a non-linear gain [4] (fig. 1).

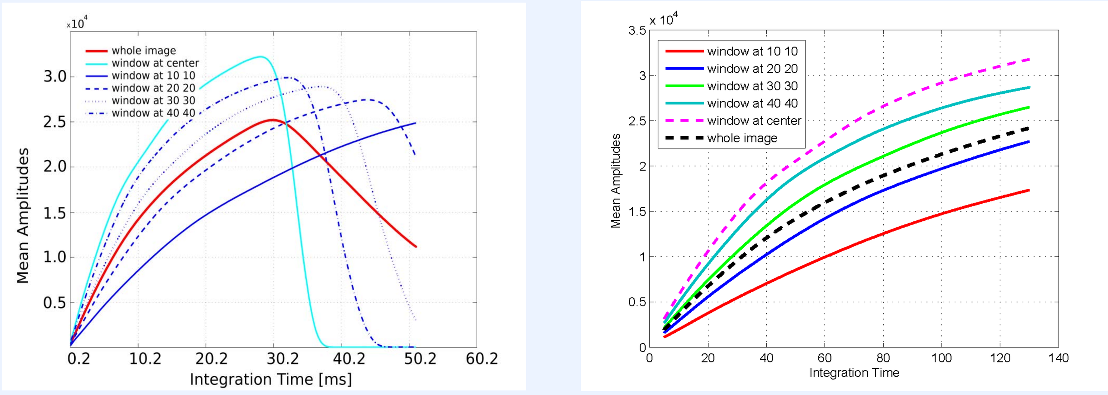

Figure 1: Mean intensity values of one scene over different integration times and at different regions of the image (left). On the right the subsection of the data from the left image is shown which was used to set up the mapping.

A saturation dependend term is added to equation 1:

$$A_{final} = A_{spec}c - S_{saturation}(A_{spec}, c, o) \qquad (2)$$

- $S_{saturation}$: saturation dependend term.
- o : external light sources (daylight, lightbulbs etc.).

The saturation level of each single pixel is not provided by the camera. For each integration time one multiplier is computed which is applied to all intensity values (eq. 3).

$$A_{itime} = A_{final}S_{itime}(t_i) \qquad (3)$$

- A_{itime} : Amplitudes, scaled by integration time.
- S_{itime} : mapping vector.
- t_i : integration time.

Because the saturation level of the pixels is not constant over the whole image, a compromise has to be made when setting up the mapping:

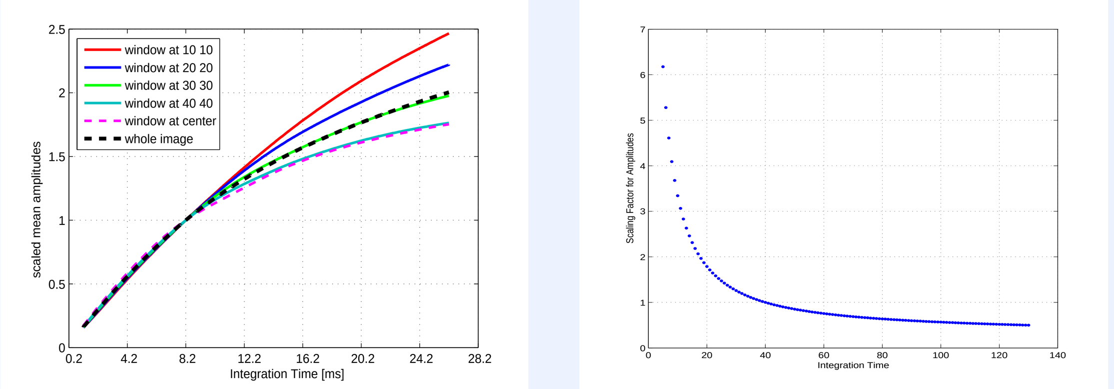

Figure 2: Comparison of the amplitude gain within different image regions (left). On the right the finally used scaling factors (corresponding to the gain over the whole image) is shown.

The method was evaluated using two different scenes:

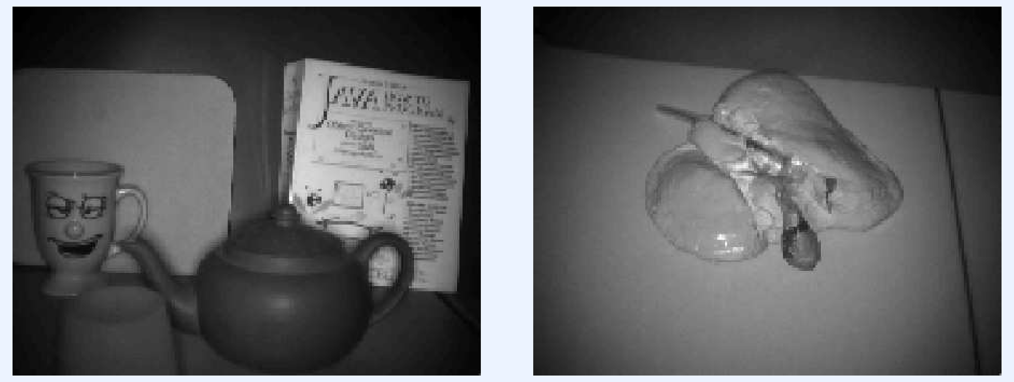

Figure 3: Example images for evaluation of scaling depending on integration time.

Results show a stable mean value within the intensity images, remaining deviations are due to the inhomogeneous gain (fig. 4).

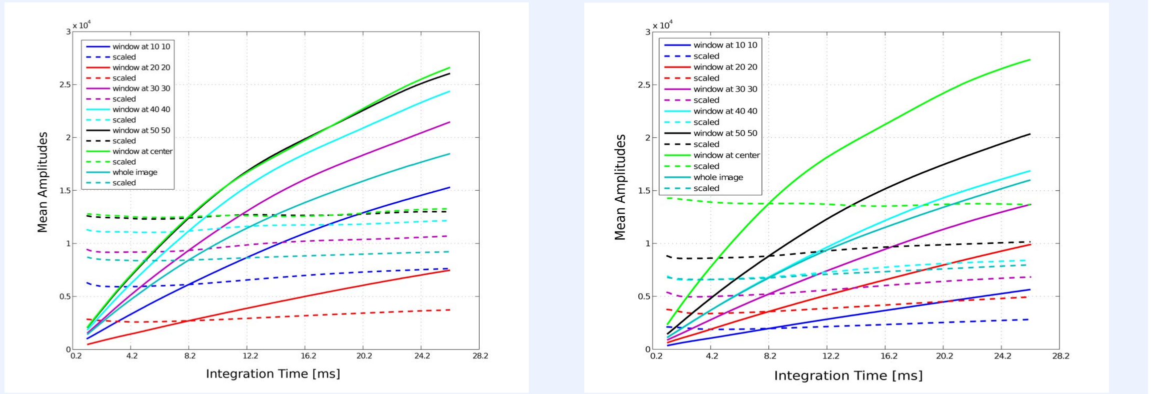

Figure 4: Scaled (dashed) and unscaled (line) mean intensities derived from the image sequence corresponding to fig. 3.

Distance Related Bias

Estimate for the attenuation of the amplitudes depending on the distances:

$$A_{acquired} = I_{src}\frac{1}{(2d)^2 + 1} \qquad (4)$$

- $A_{acquired}$: acquired amplitude value.
- I_{src} : intensity emitted by light source.
- d : distance between camera and object.

Decay was measured for several integration times (fig. 5 left). The measurements where inverted and scaled to overlay each other (fig. 5 right).

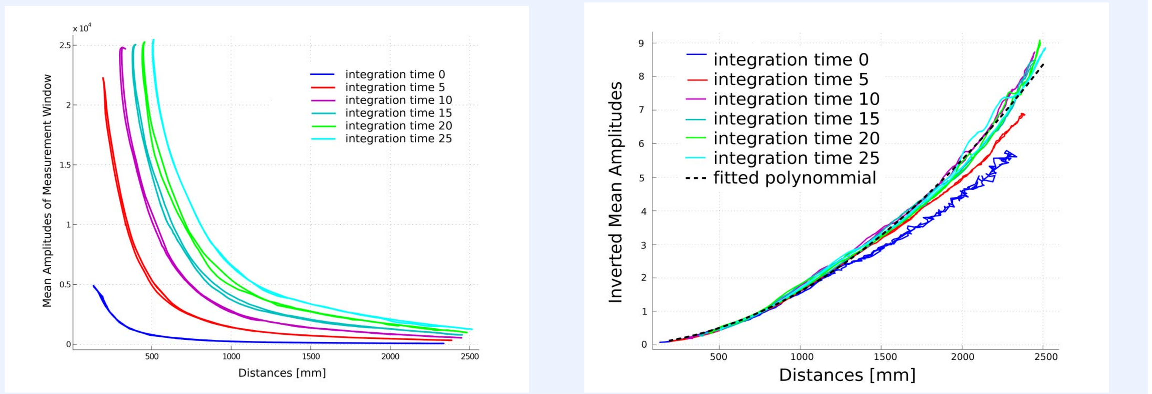

Figure 5: Setup for acquisition of the reference decays (top). The acquired decays (left) and the inverted and overlaid decays (right).

A polynomial $P_{dist}(d)$ of order three was fitted through the scaled values. The amplitude values are scaled by $P_{dist}(d)$:

$$A_{corrected}(i, j) = A_{acquired}(i, j)P_{dist}(d(i, j)) \qquad (5)$$

- $A_{corrected}(i, j)$: the scaled amplitude at position (i, j).
- $A_{acquired}(i, j)$: amplitude at position (i, j).
- $d(i, j)$: distance value at position (i, j).

For evaluation the acquired reference decays were scaled (fig. 6) and real scenes were investigated (fig. 7). A combination of both methods improved the results even more.

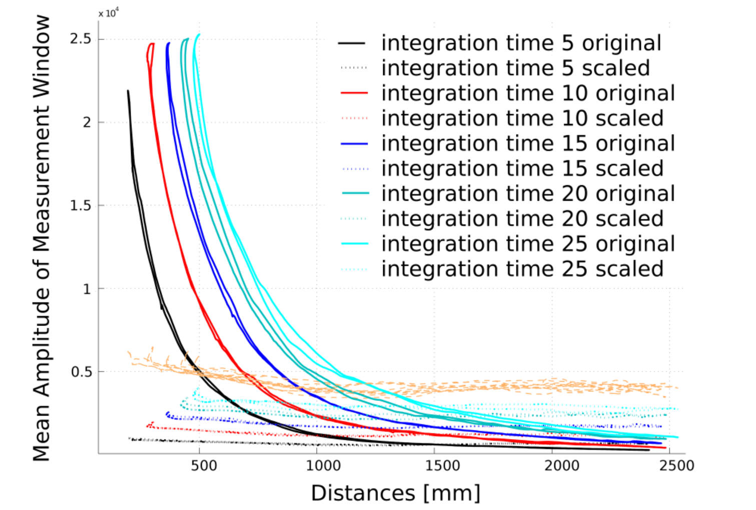

Figure 6: Comparison of unscaled (line) and scaled (dotted) amplitudes. The dashed orange lines around 0.5 are the scaled values with additional integration time scaling.

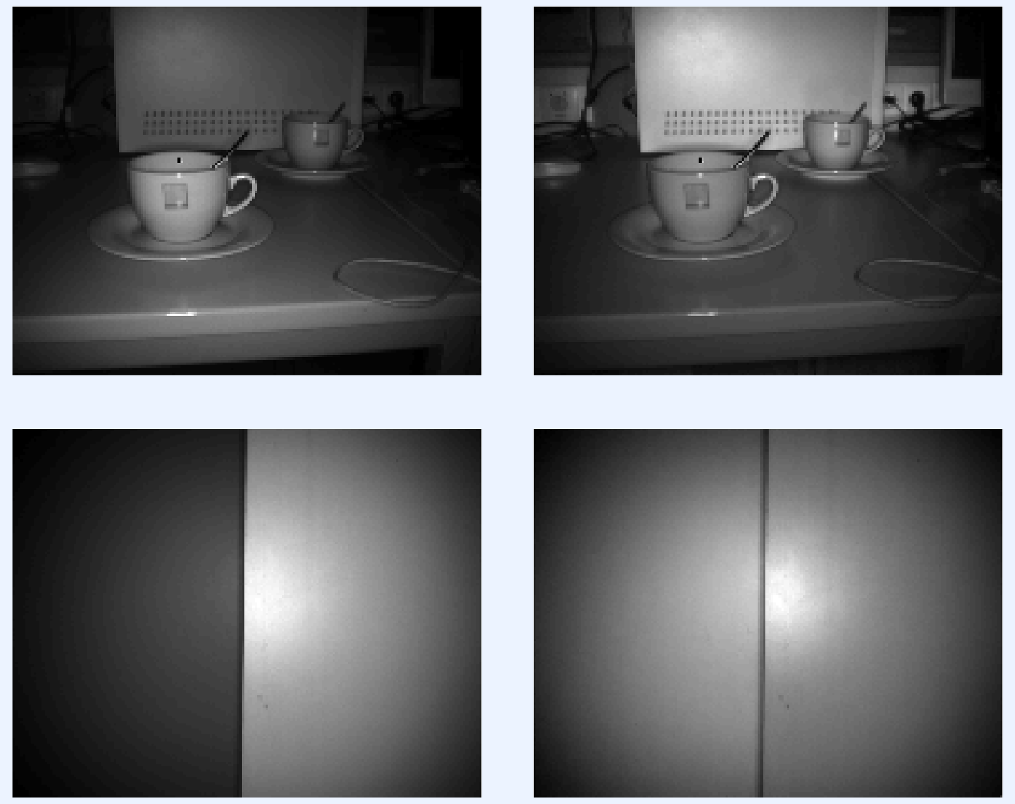

Figure 7: Images of two scenes without (left) and with distance scaling applied (right). The lower image shows two identical boards at different distances. With scaling applied, the intensities lie within comparable ranges.

Specular Reflections

- Specular reflections lead to bad visualizations (fig. 8 top).
- A threshold a_t is defined and all values $a_i > a_t$ are set to a_t.
- Maximum based determination of a_t can lead to loss of information (fig. 8 left).
- Using histograms, optimal values for a_t can be determined (fig. 8 right).

Figure 8: Correction of specular reflection. Original image (top). Scaling with $a_t = 0.9A_{max}$, A_{max} being the maximum intensity (left), within the bright region all information is lost. On the right an approach using the histogram of the image.

Conclusion

- Standardization of the amplitude values of ToF-cameras is possible.
- Robust parameterization of processing methods is possible, when applying the proposed methods for amplitude standardization.
- Further effects like inhomogeneous scene-illumination have to be investigated.
- Cameras from different manufacturers should be compared.

Support

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References

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