Resolution enhancement of large pixel PMD sensors

Henrik Lietz, Martin Kreh, Philipp Albrecht, Jörg Eberhardt

Laboratories for Lighting Technologies and Technical Optics, University of Applied Sciences Ravensburg-Weingarten

mailto: henrik.lietz@hs-weingarten.de

PMD cameras allow fast detection of three-dimensional environments. With it, PMD sensors give out a grayscale image and a distance image at the same time. Because of its operating principle, only low-resolution images are available. This work describes an approach how to increase the spatial resolution at the expense of temporal resolution.

1 Introduction

In general, PMD (Photonic Mixing Device) cameras are suitable for non-contact detection of three-dimensional objects with low contrast surfaces. These cameras calculate simultaneously the reflectance of an object surface in gray values and the distance to that surface in length dimensions. However, relatively large pixels (up to hundreds of µm) are needed in order to separate the desired signal from background noise. Especially for outdoor applications, since there exists a high amount of ambient light because of the solar spectrum. From two-dimensional image detection, several methods for increasing resolution are known. So-called super-resolution (SR) algorithms superimpose a sequence of low-resolution (LR) images to one high-resolution (HR) image. This work describes an approach that transfers these SR algorithms to PMD cameras with large pixel sizes to increase their spatial resolution. Resolution enhancement in this context means the ability to transfer object details, not only to increase the number of pixels in the image.

2 PMD camera

A PMD camera can be divided in 4 main components: light source, imaging optics, PMD sensor and electronic readout circuit (Fig. 1).

An active light source emits periodically modulated light that hits the objects surface. This reflects a part of the light that is now reduced in its amplitude and shifted in its phase. Within the detector the emitted and reflected light are compared. Out of the phase shift between the two signals, the distance is calculated. This is done for each pixel within the PMD-camera and thus allows the reconstruction of the objects surface.

In this case, the PMD camera O3M150 from ifm GmbH is used, which is optimized for outdoor applications. Because of its large pixel dimension it reaches a spatial resolution of only 64 x 16 pixels. Besides being able to reduce the pixel size, the resolution can be increased virtually by SR-approaches. This has the advantage that the sensitivity of the sensor is not reduced. This is an important factor, especially for PMD cameras, since the light emitted must be separated from the ambient light.

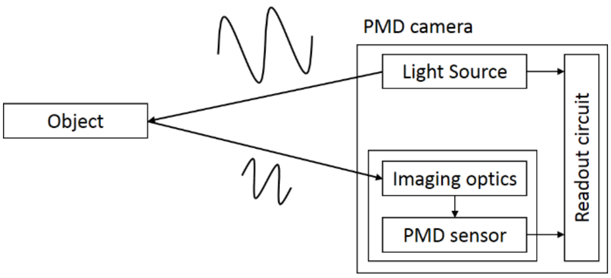

Fig. 1 *Working principle of a PMD camera with its 4 main components.*

3 Geometrical super-resolution

The term super-resolution describes a variety of methods for increasing resolution of imaging optical systems. In this work, we only consider multi-frame SR methods for increasing spatial resolution. These methods combine a sequence of LR images to a HR image with additional object information. For that, the LR images need to be displaced translational at a fraction of the sensors pixel size relatively to each other. Ultimately, SR algorithms increase the spatial resolution at the expense of temporal resolution.

Several image reconstruction algorithms are available to superimpose the LR images, such as bicubic interpolation (BicInt), iterated back projection (IBP) from Irani et al. [1], robust SR (RSR) from Zomet et al. [2] and structure-adaptive normalized convolution (Str-Ad NC) from Pham et al [3].

4 Experimental setup

The PMD sensor is mounted on a XY-translation stage separated from the imaging optics. The stage is shifted at fractions of the sensors pixel size in both directions, horizontal and vertical, using micrometer screws.

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The static measurement target includes four individual geometries on the left side and a grid of 3 x 3 squares on the right side (Fig. 2). In this work, only the grayscale (amplitude) images of the PMD camera are under investigation.

Fig. 2 *Measurement target (qualitatively) to demonstrate the increase of resolving power.*

5 Results

Subjective comparison shows an increase in reconstructed object information, depicted in Fig. 3. The geometry of the figures on the left side are better to identify. The squares in the bottom right corner are noticeable as separated objects.

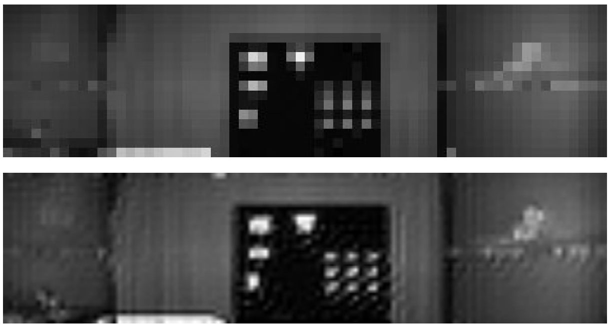

Fig. 3 *Object scene with the measurement target. Top: LR image. Bottom: SR result of the RSR method out of 9 LR images.*

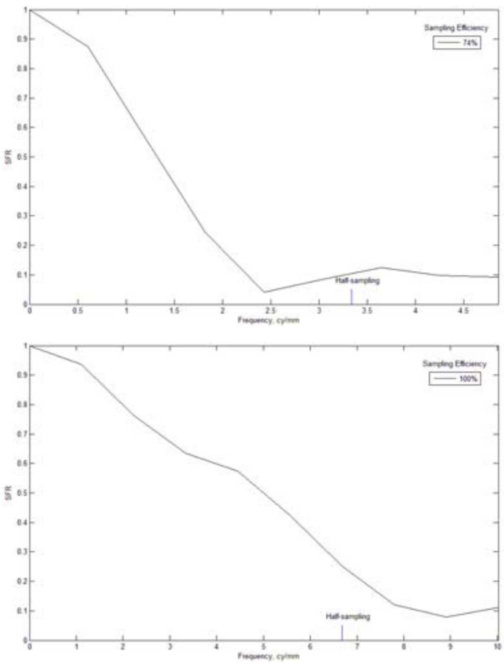

Fig. 4 *SFRs of the LR image (top) and SR image (bottom), calculated by the slanted edge method.*

In order to evaluate the resolution enhancement objectively, the Spatial Frequency Response (SFR) has been measured with the slanted edge method. The determination of the SFR is one way to measure the spatial resolution of an optical system based on the ISO12233 standard. It measures the frequency response of all spatial frequencies that the image contains. Since the SFR is determined from camera images, all degradation components of the entire optical system are included (optics, sensor and readout electronic). Comparing LR- and SR-images shows a significant improvement in the transferred contrast, as Fig. 4 shows. The SFR curve of the SR image runs much flatter and shows that higher-frequency components can be resolved.

Tab. 1 shows a comparison of the SR methods announced in section 3. The best results achieved the robust SR (RSR) from Zomet et al. [2]. Here, the resolving power is 3.7 times higher than the LR image that generates the PMD camera with standard image acquisition. The comparison shows the resolvable spatial frequency at a contrast value of 10% for the camera output and the SR images with 9 input images.

SFR [LP/mm]	BicInt	IBP	RSR	Str-Ad NC	PMD Output
4 input images	6,12	7,04	7,13	4,16	2,25
9 input images	5,83	7,48	8,33	5,12	

Tab. 1 *Comparison of the spatial frequency at a contrast value of 10% for several SR-algorithms.*

6 Evaluation

As we can see in Fig. 3 and Fig. 4, there is a significant improvement in capturing higher resolved details in the object scene. This subjective impression is confirmed by the SFR measurement. Where the SFR at 10% is 2.25 LP/mm for the input image, it increases to 8.33 LP/mm for the RSR-approach.

The SR-results were calculated with the super-resolution software “LCAV” from EPFL.

The SFRs were determined with the slanted edge method of P. Burns’ Matlab script “sfrmat3”. This is based on the ISO 12233 standard for slanted edges.

Literature

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