CALIBRATION OF A 2D-3D – CAMERA SYSTEM

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Keywords: PMD-Camera, Tof-Camera, Scanning, Camera, Calibration, architectural recording

Abstract:

The demands and needs of 3D information are continuously increasing. More and more professional branches realize potentials to improve their field of work. In consequence of this trend, new methods and technologies are developed which cost just a fraction of conventional measurement techniques like terrestrial laser scanning.

This paper describes a 2D-3D-camera system which makes it possible to obtain real colored 3D-point clouds of the environment with up to 10 frames per second. The components are shortly introduced with focus on the technology of the PMD-camera. An overview of some important points concerning the calibration of the 2D-3D-camera system is presented and calibration results are shown.

1. INTRODUCTION

An ongoing aim in our society is to make life safer, easier and more efficient. To achieve these 3D information of our environment are an essential condition. So far obtaining 3D information of the environment has been expensive and time-consuming. Since some years a lot of new technologies are presented which give the possibility to measure the environment in a much faster and cheaper way. One big technical achievement was the invention of the Photonic Mixer Device (PMD) that makes it possible to measure distances in every single pixel of an array. This technology opens up new opportunities to acquire 3D information. The so called PMD-cameras which are operating with this technology are mainly implemented in gaming industry, automotive industry, mobile robotics and more. Our goal is to investigate if PMD-cameras could be used to measure buildings. To answer this question a 2D-3D-camera system was constituted. The components of this system are a 2D-camera and a PMD-camera. In [Scherer2009] it was shown how the system may be used integrating different measuring functions like tacheometry, scanning and photo. Precondition for the functionality of the system is a sufficiently good calibration.

Section 2 gives an overview of related work. The hardware of the 2D-3D-Camera system is presented. Furthermore the measurement principle of the PMD-Camera is described. Some important aspects concerning the calibration of the camera system are shown in Section 3. Following this, section 4 provides real colored 3D-point clouds as a result of the calibration. Up from this point software technologies well known from the point clouds produced by laser scanning are available. They can be adapted to the point clouds gathered with the 2D-3D-Camera system. Finally section 5 gives conclusions and insights.

2. HARDWARE

2.1 2D-3D-Camera system

The 2D-3D-camera system consists of an industrial 2D camera and a PMD-camera. As can be seen in Figure 1 the 2D-camera is mounted on top of the PMD-camera. For using the camera system single-handed a Glidecam is applied. Hence a dynamic handling and a smooth movement of the whole system in space can be realized while recording like a video-camera at a high frame-rate. The combined cameras make it possible to calculate RGB colored 3D point clouds.

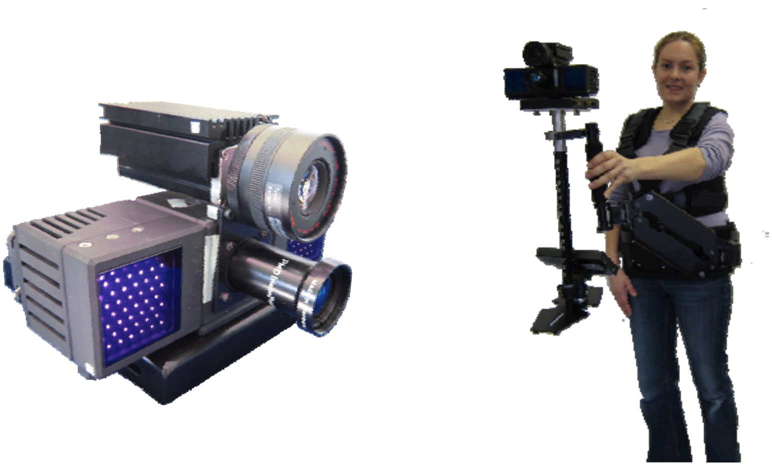

Figure 1: 2D-3D-Camera system

The PMD-camera provides distance information to compute 3D coordinates. With help of a pixel transformation pixels are transformed from the PMD-camera system into the 2D-camera system. In this way point clouds can be implemented.

2.2 Operation principle of the PMD-Camera

It is very important always to be aware that the chip of the PMD-camera incorporates thousands of rather individual tiny electronic distance meters. Their nature and their quality define the quality of the 3D-point coordinates. In order to calibrate this chip in the right way the mode of operation of the pixel has to be understood and discussed up to a certain point. This section shows the simplified operation principle of the PMD-camera. The applied PMD-camera is called CamCube 2.0 (PMD technologies, Siegen, Germany). Important parameters are shown in Table 1.

Table 1 : Features of the CamCube

Parameter	*Value*
Pixel	204 x 204
Field of view	40° x 40°
Illumination Wavelength	870 nm
Frame Rate	*25 fps*

The used CamCube 2.0 consists of two transmitting units with 42 LED's each and a receiving unit. Inside the receiving unit the pixel array is located; it consists of 204 x 204 pixel that amount to 41616 pixels in total. The PMD-camera is based on a modified phase difference method to measure distances.
The transmitting units send the optical measuring signal with a carrier wavelength of 870 nm (infrared waves). This measuring signal is modulated in amplitude with a special modulation frequency. In basic setting this modulation frequency amounts to 20MHz. The almost rectangular measuring signal travels to the object, after it is reflected it travels back to the camera. Afterwards the reflected measuring signal permeates the lens system of the PMD-camera and reaches a pixel. This device has a light sensitive area and is able to set electrons free depending on the amount of incident light (photon). Figure 2 shows a profile of a

PMD pixel. Such a pixel consists of two modulation gates, two separation gates and two readout diodes. Special feature of a PMD pixel is the possibility to distribute generated electrons onto different readout diodes A and B. This distribution process is controlled by an electrical signal which is operating via the modulation gates A and B to modify the potential distribution insight the PMD pixel.

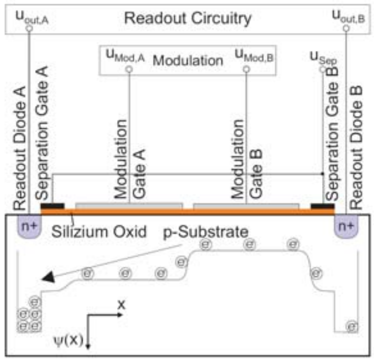

Figure 2: PMD pixel structure [Albrecht2007]

Hence generated electrons can be moved to readout area A or readout area B depending on the potential distribution insight the PMD pixel. The electrical signal that controls the potential distribution corresponds to the modulation frequency. Consequently the name PMD (Photonic Mixer Device) pixel describes the working process insight a PMD pixel, the mixing of electrical and optical signal. The electrons are integrated according to a predefined integrationtime. The resulting voltages at both readout diodes A and B are saved. This whole procedure is done four times, every time the signal is shifted by 90 degrees. Finally 8 measured voltages exist. These are used to compute samples A1, A2, A3, A4 as differences between readout voltage A and B. Furthermore the samples ΣA1, ΣA2, ΣA3, ΣA4 are calculated as sum of readout voltage A and B. The distance can be computed according to equation 1 and 2 by using four samples A1, A2, A3 and A4.

$$\varphi = \arctan\left(\frac{A_1 - A_3}{A_2 - A_4}\right) \qquad d = \frac{\lambda_{\text{mod}}}{2} \cdot \frac{\varphi}{2\pi} \tag{1}$$

in which

$\lambda_{\text{mod}} =$ modulation frequency $\quad d =$ distance $\quad \varphi =$ phase shift.

Based on the derived samples it is also possible to calculate the amplitude *a* of the signal and the offset *b* for each single pixel, see equation 3 and 4. The offset represents the gray scale value.

$$a = \frac{\sqrt{(A_1 - A_3)^2 + (A_2 - A_4)^2}}{2} \qquad b = \frac{\sum A_1 + \sum A_2 + \sum A_3 + \sum A_4}{4} \tag{3}$$

Thus one measurement of a PMD-camera delivers three information for each pixel: distance, amplitude and intensity. Both, amplitude and intensity can be used to evaluate and correct measured distances.

3. CALIBRATION

In this section the calibration of the 2D-3D-camera system is in focus. At the beginning an overview of possible systematic errors is given. This should point out the complexity of the whole calibration process.

3.1 Overview

The implemented system consists of a 2D-camera and a PMD-camera. The following Table 2 demonstrates the complexity of the calibration process. It is important to keep in mind that the PMD-camera calibration has to be a mixture of a normal camera calibration and a distance calibration, due to the fact that a PMD-camera incorporates both devices. The challenge of the calibration process is to develop calibration methods which make it possible to separate between 2D-camera- and distance calibration.

Table 2 : Calibration overview

Effect	Reason	Consideration / Calibration
1. 3D-camera		
a) Inbuilt influences		
Distance measurement		
cyclical error	harmonics rectangle-sinus	periodical numeric correction
internal crosstalk, scattering	multiple reflection during optical projection	partly efficient functional model existing
saturation	daylight / constant light	Suppression of Background Illumination (SBI)
additive constant (zero error)	electrical zero point and / or mechanical zero point	calibration
additive correction	different courses, e.g. focus	numerical correction
scale correction (small effect because of short distances)	frequency correction	numerical correction (mixture with additive correction)
asymmetrical pixel illumination (partly analogous to phase inhomogeneities at EDM)	varying surface of active pixel size	accept, educed by finger structure of the PMD-pixel
temperature stability	mainly outside temperature	correction function, temperature sensor
warm-up effects	mainly inside temperature	correction function / wait
long-term stability	frequency drift due to aging	tendency from repeated calibration
blurred pixel projection	focusing	calibration for other measuring range
varying reflectivity: tilted ray incidence or background color	intensity of the reflected signal	correction function / different integrationtime
Angle measurement		
intrinsic orientation, distortion	optical projection, pixel shape	calibration
Interdependence between direction of incident ray and signal phase	large pixel surface (finger structure of the PMD-Pixel)	accept loss of accuracy at direction -> 2D-camera
b) Errors caused by the object		
distance error	differences in reflectivity	negligible
over- / underload	too long/short integrationtime	adapting integrationtime
direction inaccuracy	different reflections inside pixel areas at objects	accept
external crosstalk, scattering (superimposition)	multiple reflection at surfaces	reduction by analyzing frame order
2. 2D-camera		
error in direction	distortion	calibration
intrinsic orientation	-	calibration
Combination / 2D-3D-camera system		
a) Relative orientation	-	calibration
Shutter synchronization between 2D- and 3D-camera (triggering)	identical pictures during dynamic use	hardware triggering

3.2 3D-camera repeatability

Before showing calibration results the repeatability of the CamCube 2.0 is analysed. In Figure 3 the results are shown. The measurements were made against a white flat surface.

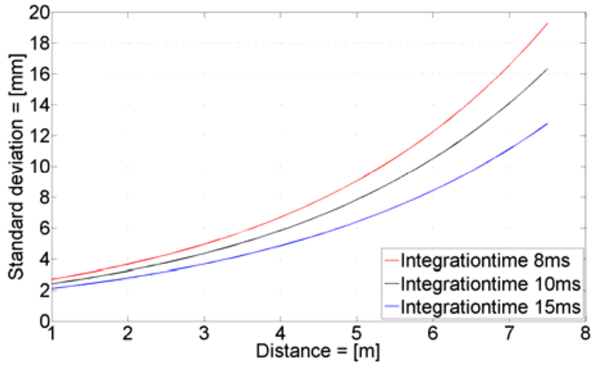

Figure 3: Repeatability at different integrationtimes.

The dependence between repeatability, distance and integrationtime is obvious.

3.3 Calibration results

In the following some results of the PMD-camera calibration are introduced, starting with the calibration of the temperature stability. It is well established that atmospheric conditions effect distance measurements with EDM. For that reason the performance of the PMD-camera was investigated inside a climatic chamber for 17 hours. During the investigation temperatures between 0°C and 30°C were adjusted. Every 2 minutes three measurements were made. To get more information about heating of the PMD-camera, a temperature sensor was fixed at the camera housing. At the housing of the PMD-camera a temperature could be measured 8 kelvin higher than the environmental temperature. Figure 3 shows the housing temperature and the measured distance versus time.

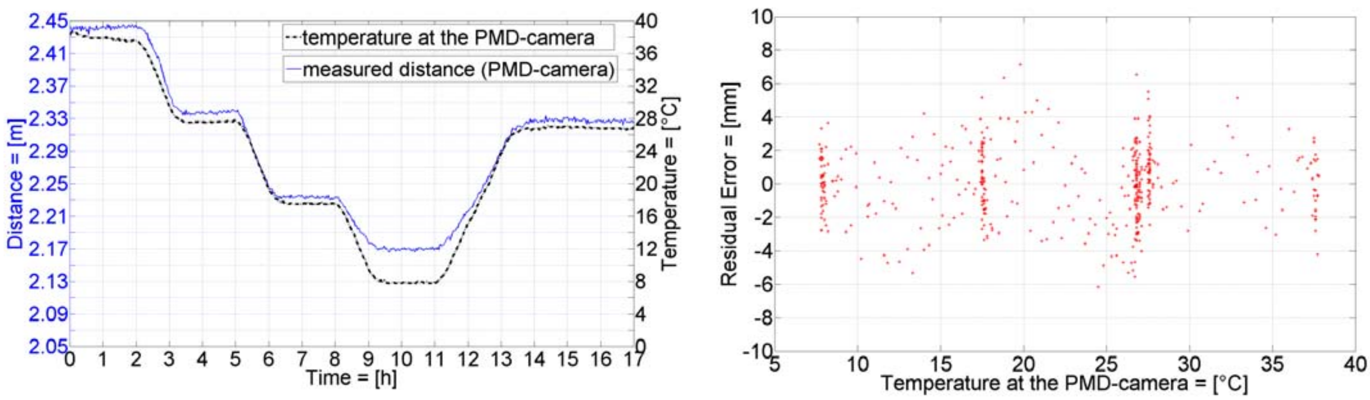

Figure 3: Temperature influence on distance measurement.

As can be seen temperature and measured distance are highly correlated. Applying the calculated correction function onto the distance measurements, results in residual distance errors between ±7mm. (Figure 3 (right)) The cyclic error is another important part that had to be investigated. To test the PMD-camera for a cyclic error reference distances between 1.8m and 7.5m were analysed. Distances closer than 1.8m lead to distance measurement problems, because of overexposed PMD-pixels. In this investigation 10ms were chosen as integrationtime. Figure 4 shows the distance corrections between the reference distances and the PMD measured distances. Based on these values a correction function was computed. The residual distance errors are shown in Figure 4 on the right side.

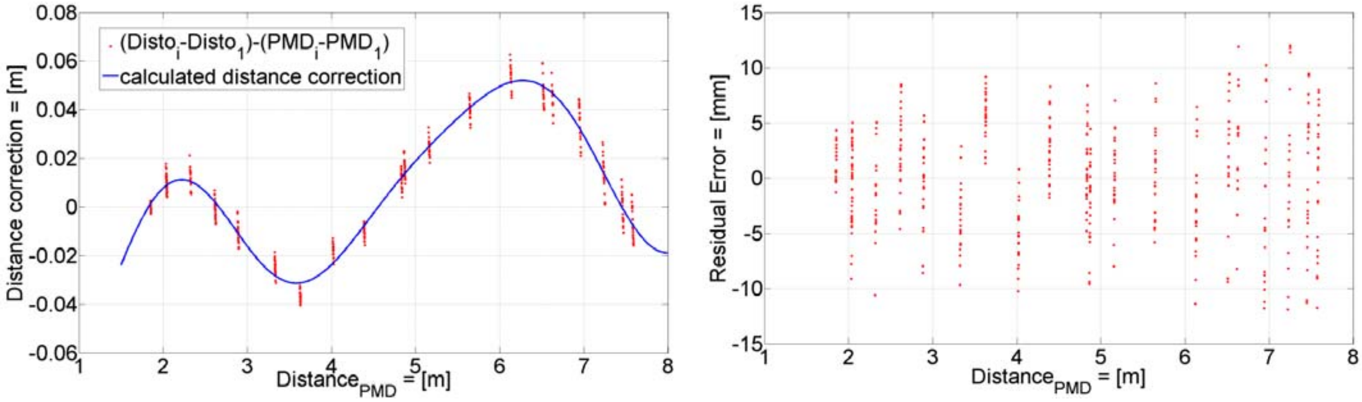

Figure 4: Cyclic error and residual error after applying correction.

Beside the distance calibration the photogrammetric calibration has to be done. Within the investigation the radial and tangential distortion parameters, skew, principle point and focal length are calculated. These calculations are performed by using a plane test field with 80 reference points. Through the use of reflex slides it is possible to detect the reference points insight amplitude images taken by the PMD-camera. Figure 5 (left) shows the effect of radial and tangential distortion.

Figure 5: (left) Calculated distortion of the PMD-camera,
(middle, right) Pixel transformation between PMD-camera and 2D camera.

After calibrating the cameras regarding distortion, the relative orientation between 2D- and 3D-camera has to be determined. Consequently transformations between PMD pixels and 2D-camera pixels can be computed. So it is possible to combine both cameras and to adapt the higher pixel resolution of the 2D-camera to the PMD-camera. In Figure 5 (middle and right) the intensity image taken by the PMD-camera and the RGB-image taken by the 2D-camera are shown. The red dots illustrate pixels that are transformed from the PMD-camera into the 2D-camera image.
One big advantage of the 3D-camera is the possibility to capture a whole scene just in one shot. Thus this type of camera is ideal for dynamic usage. To generate colored point clouds the PMD data and the corresponding 2D image are needed. Frame rates up to 10 fps can be realized by the PMD-camera with an integrationtime of 10 ms. The precision of the synchronization (triggering) between the 2D- and the 3D-camera is crucial for the accuracy that could be reached by a later combination of the data. There are two possibilities to implement the camera synchronization; these are software triggering and hardware triggering. For this application hardware triggering was chosen. This type of triggering fulfills the high synchronization requirements. Within this project a master thesis [Ma2011] was written, which investigated the synchronization and the data storage.

4. CONCLUSION

After the calibration of the 2D-3D-camera system it is possible to create RGB-colored point clouds. One example is shown in Figure 6.

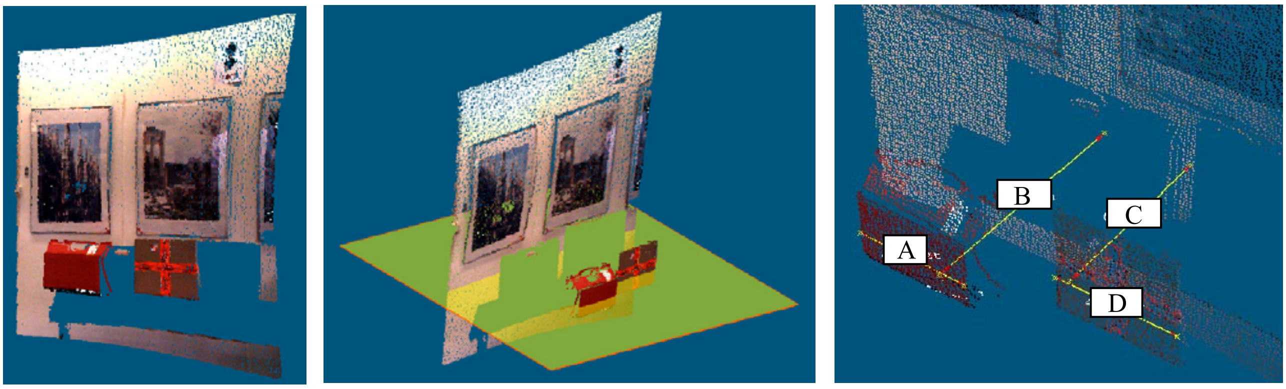

Figure 6: (left) RGB colored point cloud, (middle) with sectional plane, (right) example measurements.

In Table 3 calculated short distances from 3D-coordinates are compared with the reference distances. During single measurements this accuracy cannot be reached.

Table 3 : Calculated distances

	A	*B*	*C*	*D*
PMD distance	41,7 cm	86,1 cm	67,8 cm	43,9 cm
Reference distance	42,3 cm	86,4 cm	67,4 cm	43,6 cm

The used CamCube 2.0 is currently the PMD-camera with the highest pixel resolution. An overview on effects that can influence the accuracy of the 2D-3D-camera system is presented. Reasons for these effects were stated and aspects how to consider or calibrate them are shown. The complexity of the whole calibration process was pointed out. Furthermore the necessity and the possibility of the calibration were illustrated. It has been shown, how it is possible to create RGB colored point clouds.

Future work will concentrate on the transformation of the point clouds into one global coordinate system. In this process the high frame rate of data acquisition enables new developed methods for registration.

5. REFERENCES

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