A Comprehensive Characterization of the Asus Xtion Pro Depth Sensor

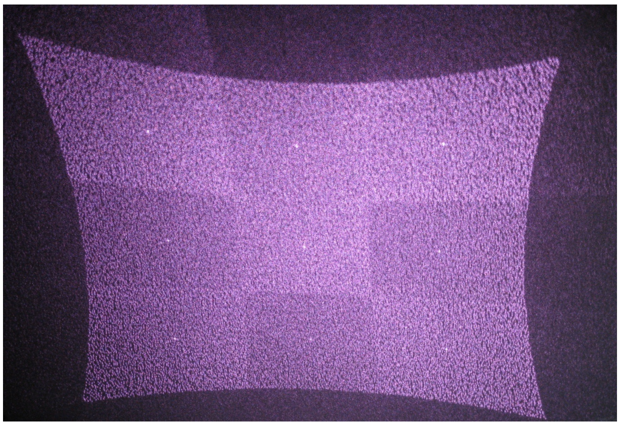
Daniel Maximilian Swoboda[1*]

1 Höhere Technische Bundes Lehr- und Versuchsanstalt Wiener Neustadt, Abteilung Informatik (Secondary Technical College Wiener Neustadt, Department for Computer Science)

* Corresponding author E-mail: i12032@student.htlwrn.ac.at

Abstract

This publication gives a comprehensive characterization of the Asus Xtion Depth Sensor. The first part shows the hardware of the Asus Xtion environment/works and compares it to other depth sensor technologies. Afterwards the software behind the hardware architecture is presented. The frameworks that are necessary for developing applications applying the sensor, especially the OpenNI framework are explained in detail. In the experimental part the measurements are presented that were made to test the accuracy of the sensor and how error-prone the depth sensor is. The next part shows the results of the experimental as statistics with tables while the last part tries to explain the results.



Photograph 1. A infrared photograph of the projected dot matrix from a structured light depth sensor[1]

Introduction

Since the introduction of Microsoft's Kinect, depth sensors for private and scientific applications became much more affordable. One of the leading companies in depth sensor technology was PrimeSense (now a subsidiary of Apple Inc.), which grouped with Microsoft to develop Kinect [2]. PrimeSense also developed the so called Carmine 1.08 depth sensor, which is the foundation for the Xtion Pro [3,4,5].
While depth sensors becoming less expensive they also found their way to low-budget and educational robotics. Sensors like the Xtion Pro are capable of capturing and processing gestures in real time, which makes them ideal for robots that should react to moving objects.
In this publication we used the Xtion Pro camera from Asus, where we wanted to find out how accurate these cheap sensors can be in a dynamic robotic environment.

1. Overview of the Hardware of the Xtion Pro

As stated earlier, the Xtion Pro uses depth sensing technology from PrimeSense. The company is well known for the cheap implementation of the so called structured light, or light coding, technology in the near infrared spectrum, an alternative to stereo camera systems which lowers the costs because already existing low priced hardware can be used [4,6].

Distance of Use	Between 0.8 and 3.5m
Field of View	58°H 45°V, 70°D
Depth Image Size	QVGA (320x240)

Table 1. Official Specifications Sheet for the Xtion Pro [7]

While the Xtion Pro only has a sensor for processing the infrared light, the Xtion Pro Live also includes an RGB Sensor for making photos and videos [7]. This is because the Xtion Pro Live is intended to be a development solution for later implementations in home computing where a RGB camera is helpful and preferable. To analyze gestures and for detecting objects with depth data this isn't necessary.

Most of the depth-data processing work is done by PrimeSense's solely developed SoC (System-on-a-Chip) so there are hardly any CPU requirements [3]. Hence, PrimSense sensors can be used on nearly every computer with minimal computational power which makes it easy for robotic projects, which are often controlled by underachieving computers.

On the other hand this restricts developers in the way they can use the data. Because almost all of the processing is done on the SoC developers only have access to the processed data.

1.1 Structured Light Technology

Structured light is a common and cheap method for getting depth data. A pattern of light is projected and recorded with a typical CMOS Sensor. Through the distortion of the pattern the depth can be calculated. Most structured light sensors change the pattern several times in one capturing frame to get more accurate results.

Because of the use of light patterns structured light sensors only produce proper results in-door and environments with controlled light conditions. In the case of PrimeSense sensors which produce patterns in near infrared interfering light can influence the performance of the sensor.

2. Using the Depth Data

Usually, the quality of the implemented software mostly affects the performance of any computer technology and is essential to get satisfying results. Especially when working with depth sensors there can be a big difference in the accuracy of the results through software.

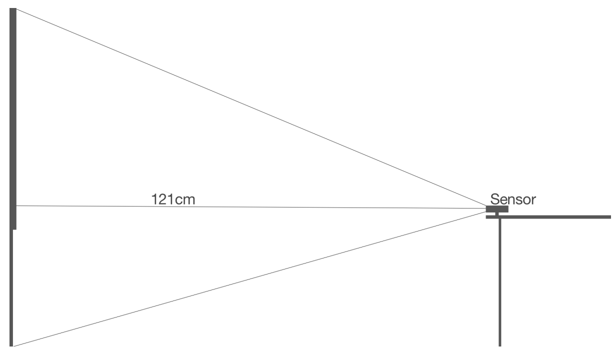
2.1 The OpenNI Framework

For sensors based on PrimeSense technology the so called OpenNI framework is the best solution because it's the largest 3D sensing development framework and PrimeSense is mainly responsible for the framework development.[7] Sadly OpenNI is no longer in development as a consequence of the acquisition of PrimeSense.

OpenNI (Open Natural Interaction) was an industry-led, non-profit organization which developed the eponymic, free OpenNI framework which provided nearly everything for developing middleware libraries and applications. The framework is written in C++ but there are also abilities to use it with Python and Java through additional libraries.

3. Experimental

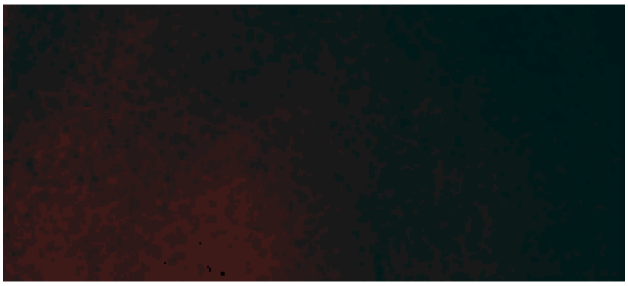
To get information and data about the accuracy of the sensor we made a testing protocol which included a variety of distances and measurement methods like direct access and calculating the arithmetical average for every point of measurement.



Graphic 1. The experimental assembly.

The accuracy was tested in a room with controllable light conditions and a flat wall. To test measurement errors at the edges of objects at the same time a pinboard was hung up in a way to cover 2/3 of the field of view of the sensor. The sensor was placed 121cm away from the pinboard, which is 1cm thick. 12 measurements were made at the shortest possible timespan after the last one and written in a csv file to make evaluation easier. Measurements were made under 78 different circumstances with different levels of light, different sources of light and different light directions.

With OpenNI you get access to every depth value for every pixel trough an array. By accessing this data we managed to get an overview of the depth maps generated by the sensor.
The first three pixel rows are not returning any results. Also the depth image is mirrored. The problem occurred on both sensors that were tested. Another noticeable fact is that the results are more inaccurate in both top edges.



Graphic 2. A visualization of the results of the measurements

4. Statistical Analysis

Several methods where used to evaluate the results and to get comparable values out of the raw data. For each condition the mean, the standard deviation, the median, the maximum and the minimum where calculated. The table below shows the results of these calculations.

	Natural Light	Dimmed Light	No Light	Frontal Light (LED)	Light from the side (LED)	Light from above (LED)	Light from above (fluorescent lamp)
Mean	1228.8	1228.1	1228.9	1228.4	1227.5	1228.1	1228.9
Standard deviation	9.9	5.8	8.5	6.6	7.1	7.0	9.4
Median	1223.0	1223.0	1223.0	1223.0	1219.0	1223.0	1223.0
Maximum	1236.0	1232.0	1232.0	1232.0	1232.0	1232.0	1236.0
Minimum	1202.0	1210.0	1206.0	1210.0	1210.0	1210.0	1206.0

Table 2. Results of the calculations under each condition, values in mm.

What is remarkable is that the median for most of the conditions is 1223 mm. Only if the light comes from the side the median drops to 1219 mm which is a deviation of 0.4%. The standard deviation fluctuates between 5.8 and 9.9. The mean fluctuates between 1227.5 and 1228.8 which is a deviation of the real distance between 17.5mm and 18.8 m. With a failure in measurement that is that stable it’s easy to correct it in a program which uses the data.

Results

The results differ in different light conditions which prompts that either the light sources are emitting infrared light in a way that it jams the CMOS chip of the sensor or that the CMOS chip is also sensitive for light in the visible spectrum. But the deviations are very small especially if one takes the median as point of reference. This makes light to a negligible factor for the accuracy of the sensor. The overall results of the measurements suggest that the sensor has an astonishing precision for it’s price and make it quite useful for any kind of project which involve middle range depth sensing.
In future more measurements of the accuracy in different distances can be made as well as testing the sensors accuracy under movement.

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