Technical University of Denmark

Mikkel Viager

Analysis of Kinect for mobile robots

Individual course report, March 2011

DTU Electrical Engineering
Department of Electrical Engineering

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Report written by:
Mikkel Viager

Advisor:
Jens Christian Andersen

DTU Electrical Engineering
Technical University of Denmark
2800 Kgs. Lyngby
Denmark

studieadministration@elektro.dtu.dk

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Abstract

Through this project, a data sheet containing more detailed specifications on the precision of the Kinect, than are available from official sources, has been created. Furthermore, an evaluation of several important aspects when considering the use of Kinect for mobile robots has been conducted, making it possible to conclude that the Kinect is to be considered as a very viable choice for use with mobile robots.

Resumé

Ved udførelsen af dette projekt er sammensat et datablad indeholdende detaljerede informationer om Kinect-sensorens specifikationer, som ikke er tilgængelige fra officielle kilder. Yderligere er vigtige aspekter, i forbindelse med brug af Kinect for mobile robotter, blevet gennemgået. Dette har ført til konklusionen at Kinect er en særdeles brugbar sensor-løsning til anvendelse i forbindelse med mobile robotter.

Table of Contents

1. Introduction

In order to successfully navigate a mobile robot, obtaining detailed information on the robots' immediate environment is a main concern. If the collected data is correct and sufficiently detailed, developers are given the opportunity to create accordingly sophisticated navigation software.

Numerous sensor technologies are available, and they each provide unique advantages for use in specific environments or situations. In addition to sensor types, the desired number of dimensions to track can vary. A simple range finder can detect a distance in 1 dimension, and more complex scanners can do 2D or 3D scan sweeps. Whereas an additional dimension greatly increases the detail and overall usability of the collected data, it also causes a major leap in the purchasing price of the sensor.

Recently a whole new type of sensor technology called Light Coding has become available for purchase at only a small fraction of the price of other 3D range finders. The technology has been developed by the company PrimeSense [1], and is currently implemented and sold by Microsoft in the "Kinect" for the game console Xbox 360.

The goal of this project is to analyse the usability of the Kinect for mobile robots, by evaluating the ability of robust data collection and general applicability to this field.

All test and measurements have been carried out in Linux on the Mobotware[2] platform, with a plugin based on open source Kinect drivers [3].

1.1 Documentation overview

This report is mainly focused on the produced data sheet in Appendix A. Thus, all main results can be derived from plots and values presented there.
For details on how the measurements were made, as well as evaluation of the results obtained, the following chapters will provide an overview.

Chapter 2: A brief explanation on how Light Coding works.

Chapter 3: Determining the resolution accuracy for spatial X/Y and depth Z coord.

Chapter 4: Finding the relation between sensor value and actual distance.

Chapter 5: Interference from use of multiple Kinects in the same environment.

Chapter 6: Other considerations of relevance when using Kinect for mobile robots.

Chapter 7: Conclusion

Appendix A: Data sheet

2. Light Coding with the Kinect

Many current range-finding technologies uses time-of-flight to determine the distance to an object by measuring the time it takes for a flash of light to travel to and reflect back from its surface. Light Coding uses an entirely different approach where the light source is constantly turned on, greatly reducing the need for precision timing of the measurements.

A laser source emits invisible light (approximately at the infrared wavelength) which passes through a filter and is scattered into a semi-random but constant pattern of small dots which is projected onto the environment in front of the sensor. The reflected pattern is then detected by an infrared (IR) camera and analyzed. In Figure 1 the sensor and the projected light pattern is shown on an image taken with an IR camera.

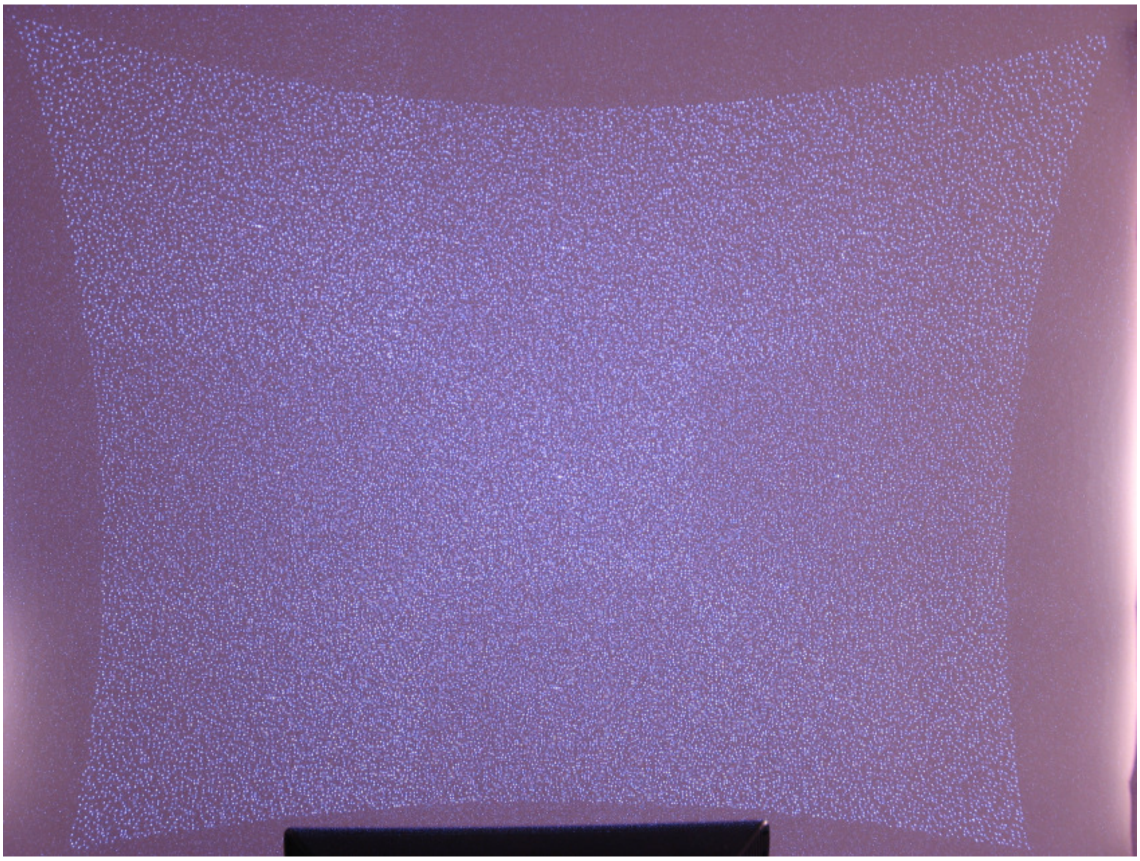


Figure 1: The projected infrared pattern [5].

Supported by the nine brighter dots in the centers of the slightly noticeable checker-pattern, the reflection of each dot is evaluated on its position. From knowledge on the emitted light pattern, lens distortion, and distance between emitter and receiver, the distance to each dot can be estimated by calculation. To achieve a rate of 30 completed scans per second, the process makes use of values from neighboring points.

This is done internally in the Kinect, and the final depth image is directly available.

3. Spatial and depth resolution

The specifications given with the reference model from PrimeSense on the depth image resolution is only for 2m distance measurements. At this range is given both spatial x/y resolution, as well as depth (z) resolution. The provided values at 2m are shown below in Table 1.

Spatial x/y resolution (@ 2m distance)	3mm
Depth z resolution (@ 2m distance)	1cm

Table 1: Provided resolution values for PrimeSense reference model

This very limited information is insufficient for evaluation in this case, as the resolution can be expected to vary with distance.

By collecting measurement data for various distances, a better insight in the resolution properties has been uncovered. The setup for the experiments is shown in Figure 2 (the corresponding depth scan can be found in Appendix B)

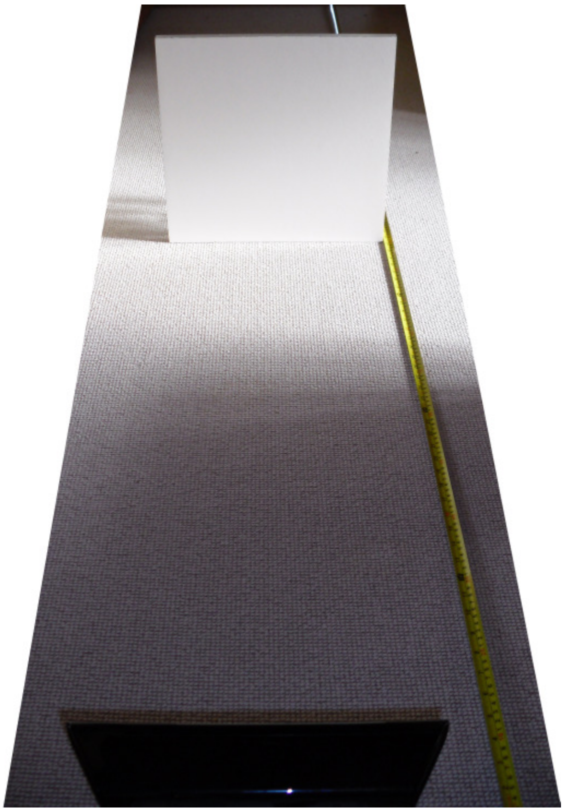


Figure 2: Experiment setup

The Kinect sensor is kept at a stationary point, and a flat plate colored semi-matte white of size 378 x 392mm (h x w) is placed (and vertically leveled) at measured distances. Because of the floor surface being a white carpet, the sensor is not able to get any usable reflections from it, making extraction of data for only the plate relatively easy. Once extracted, the data is ported to MATLAB for further analysis. An example of depth data for the plate is shown in Figure 3, where a color gradient is used to visualize the depth values.

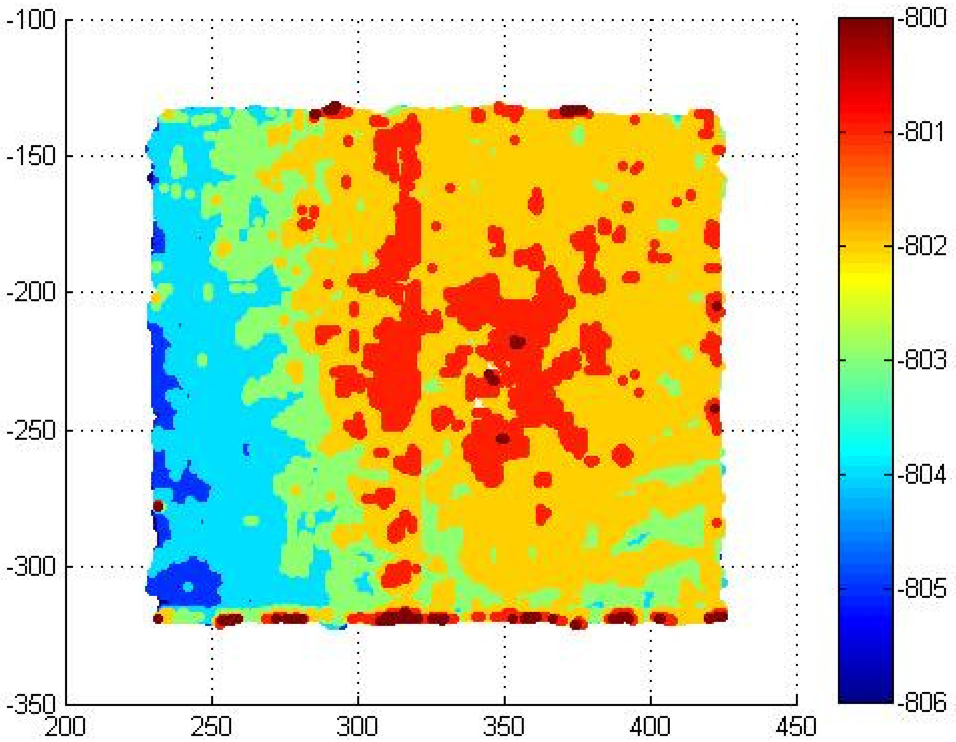


Figure 3: Depth data for the plate at a distance of 1.2m

At distances of below 1m, the reflection in the center of the plate was too bright to be properly detected. This is due to reflective properties of the white surface, and is estimated to have only a minor impact on the results. An example of this can be seen on the picture in Appendix B, or by plotting the measurement data using the MATLAB file on the CD.

A total of 40 such measurements were taken, in 0.1m interval from 0.6m to 4.6m. The overall interval is chosen to be greater than the 0.8-3.5m operation interval suggested by PrimeSense, in order to also see if these boundaries are reasonable.

3.1 Spatial X and Y resolution

With the points of measurement available in MATLAB, a small script was developed to locate the first and last pixel of value in each row and column. The interval of these test are chosen manually, to avoid problems with the edges which could occur at just the slightest rotation of the plate.

By counting the number of pixels in each row, and then finding the mean value of all rows, a good estimation on how many pixels resolution is used to detect the plate. Then the known width of the plate can be used to calculate the horizontal distance equivalent to a single pixel. The same principle is applied to the vertical resolution. A table with the calculated resolution values (and a mean) can be found in Appendix C.

The mean resolution value vs. distance proves to be very linear as can be seen in Figure 4. It is also seen that the resolution at 2m distance is very close to the one provided by PrimeSense. As the Kinect can be further manually calibrated could be one of the reasons that the value is slightly off.

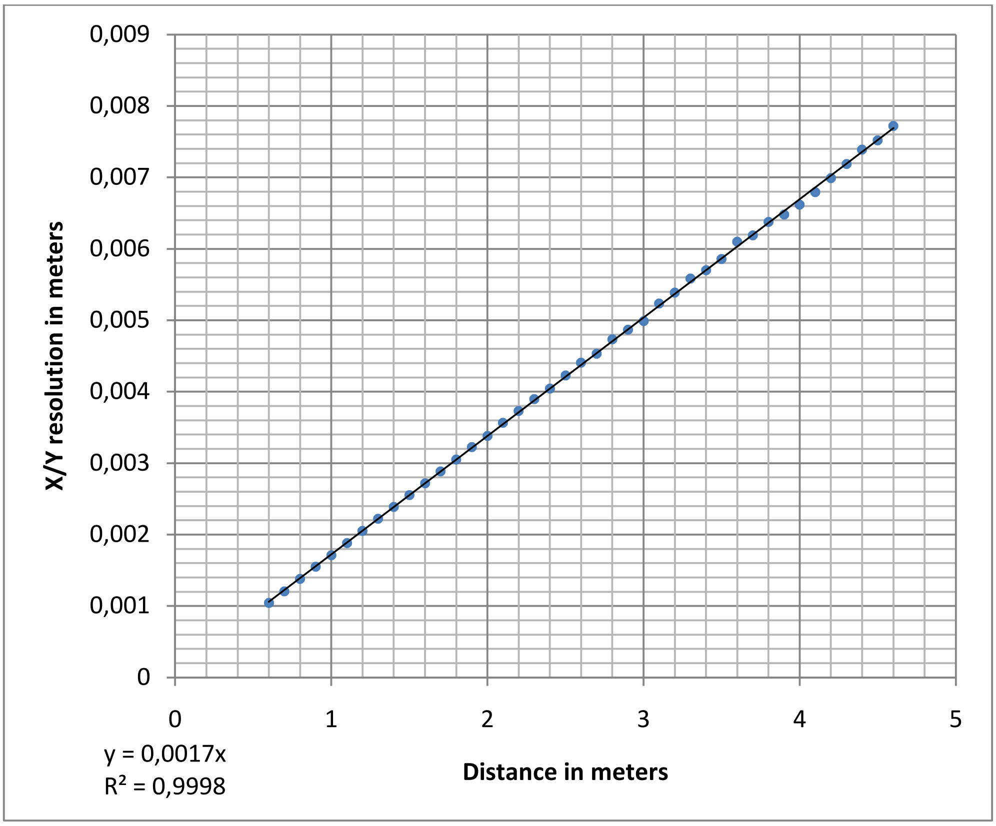


Figure 4: Spatial x/y resolution vs. distance in meters

3.2 Depth resolution

For small distances, the depth resolution can be approximated as

$$\frac{\Delta L}{\Delta N}$$

Where ΔL is a distance interval, and ΔN is the interval in measurement values for the same distance. By applying this to each of the 0.1m intervals from the measurements, a function describing the depth resolution as a function of distance is estimated as shown in Figure 5.

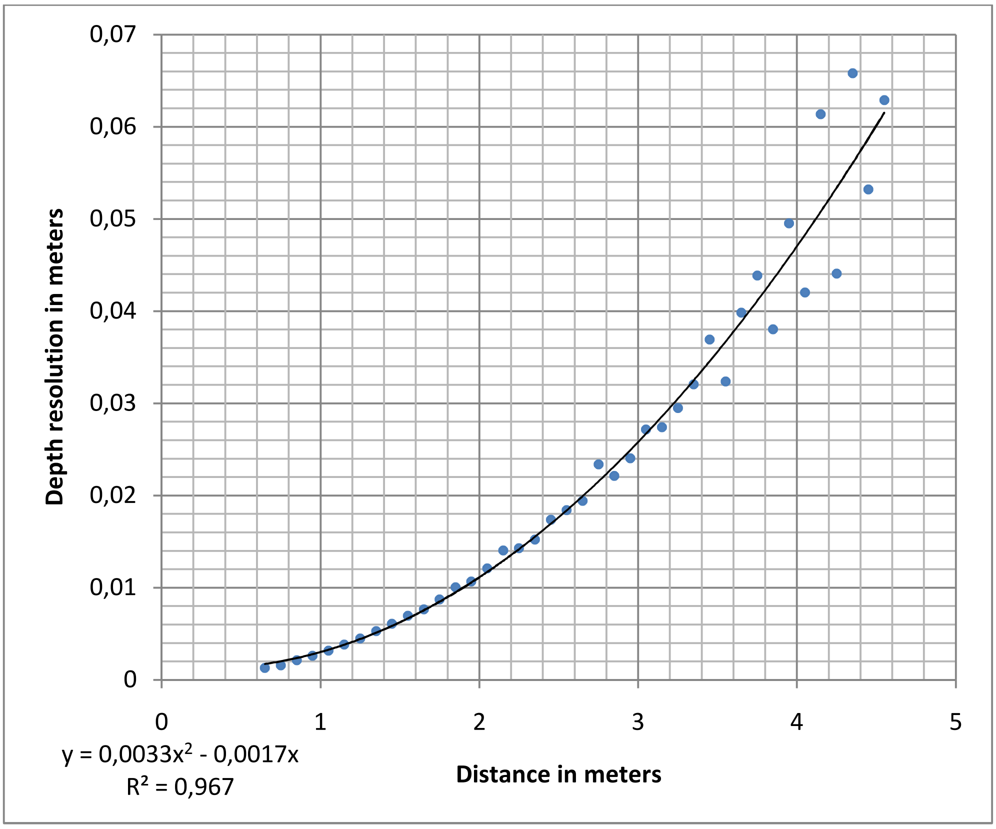


Figure 5: Depth (z) resolution vs. distance

The calculated values are listed in Appendix D.

4. Actual distance from sensor value

For each pixel in the depth picture of 640x480 px resolution is provided a depth value in the interval 0-2048 (11bit). In order to make use of this information, a relation between the sensor value and actual distance has to be established.

The approach is illustrated in Figure 6.

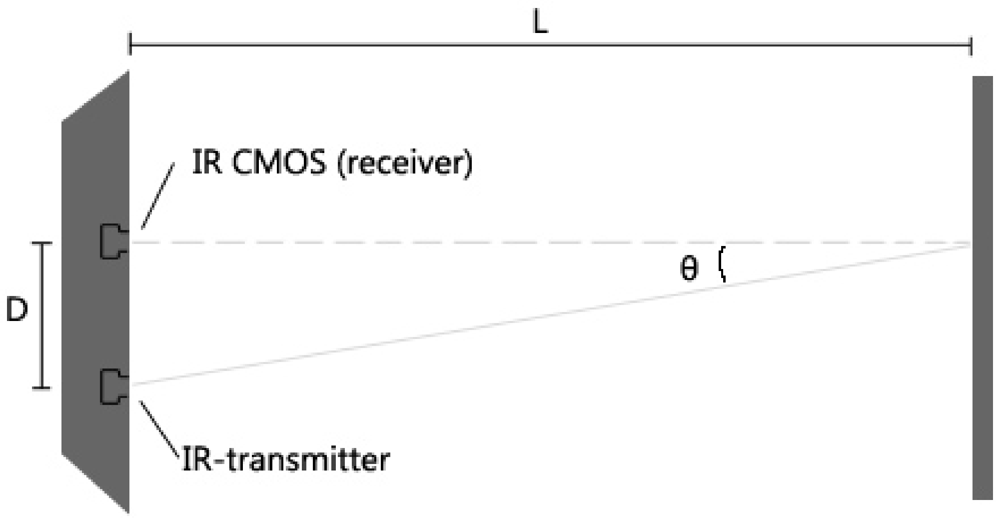


Figure 6: Diagram of the applied theory for distance measurement

The angle can be calculated from trigonometry as

$$\theta = \arctan\left(\frac{D}{L}\right)$$

Where the distance between the IR emitter and receiver is $D = 0.075m$, and L is the distance from sensor to the measured object.

By comparing the calculated angles for all of the measurements with their corresponding sensor values (N), a linear relation can be expressed as

$$N = -4636.3\,\theta + 1092.5$$

Thus, inserting the expression for θ in the above gives

$$N = -4636.3 \arctan\left(\frac{0.075}{L}\right) + 1092.5 \iff$$

$$L = -\frac{0.075}{\tan(0.0002157N - 0.2356)} \quad [m]$$

Which calculates the actual distance for a given measurement value.

A plot showing both the measured and calculated sensor values vs. distance are shown in Figure 7. The dots are the measured values, and the line is the calculated.

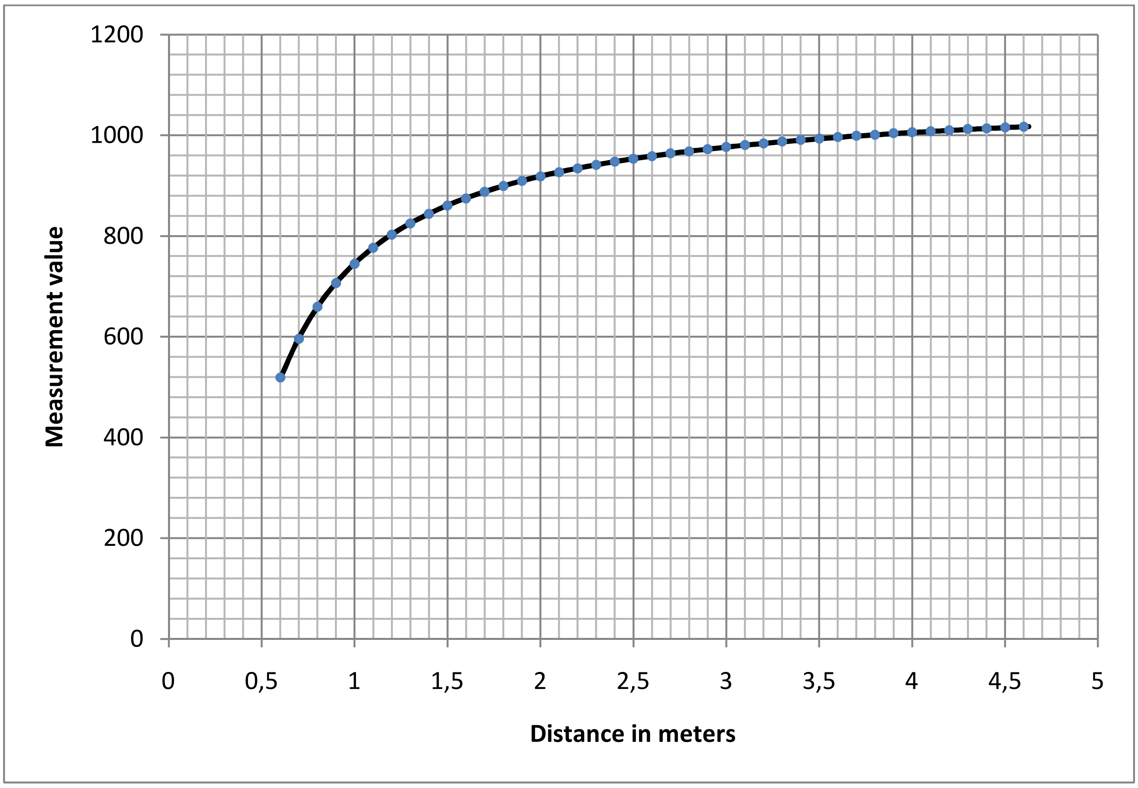


Figure 7: Measured (dots) and calculated (line) sensor values vs. distance

The equation for getting an actual distance from a measurement value is simple, and should be easily implementable in desired applications. Whereas this can be applied to any Kinect, even better results might be achievable by recalculating the relation between N and θ after calibration, which can be done each individual Kinect unit.

It is very reasonable to assume that the distance as a function of measurement value is usable for distances outside the tested interval as well. The Kinect has a build in lower threshold of around 0.4m, but no maximum.

Taking into account that the precision of the gathered data decays with distance, it should be possible to use this approach for distances from 0.4m up to as much as 6, 8 or even 10m, depending on the requirements for precision.

5. Interference caused by multiple Kinects

By placing the Kinect on a mobile robot, there is the possibility that multiple Kinects in the same area will at some point will be a noise source for one another. This can be by overlapping IR-light patters in the environment, or by directly facing another sensor and thus blinding it with IR-light.

5.1 Overlapping of projected IR-patterns

If two sensors are positioned in a way causing an overlap of the projected light patterns, both sensors suddenly have multiple "alien" dots to process. By experimenting with this issue, tests have shown that the noise is very well handled in the depth images. The Kinect flags uncertain or noisy points as being infinitely far away, without affecting the accuracy of any surrounding points (or clusters of points). In Figure 8 are shown depth images of a wall at 1m distance with different IR pattern conflicts.

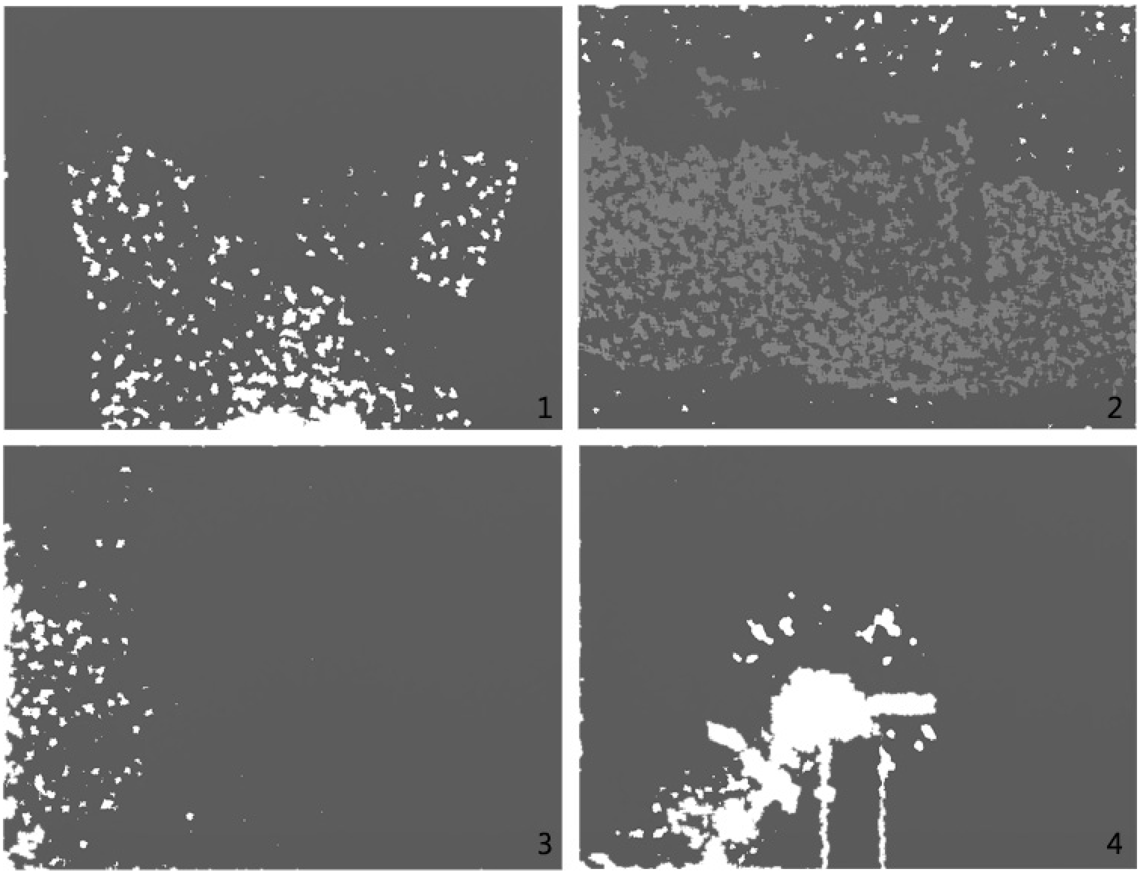


Figure 8: Depth images for sensor conflicts. White spots are detected as infinitely far away.

Image 1: Noise inducing Kinect is placed 0.6m from the wall. 0^{o} incidence difference.
Image 2: Kinects placed very close, and adjusted for calibration point conflicts.
Image 3: Noise inducing Kinect is placed 1m from the wall. 45^{o} incidence difference.
Image 4: Kinects looking directly at each other. IR-image is in Appendix E.

It is clear that the disturbance is most significant in cases where the angle difference between the two sensors is very small. Worst case is when several calibration dots (the nine brighter ones) are conflicting, as this can cause two sets of distance surfaces to be wrongfully detected as shown in Figure 9.

The results from image 2 and 4 are however difficult to obtain, as the sensors has to be placed very precise to achieve the shown conflicts. These are thus worst-case scenarios, and the situations shown in image 1 and 3 are what will be commonly seen.

By keeping the interfering Kinect in motion, the impact of the overlapping pattern was greatly reduced. This should be kept in mind for use with mobile robots, as one or both patterns will most likely be in motion during many overlaps.

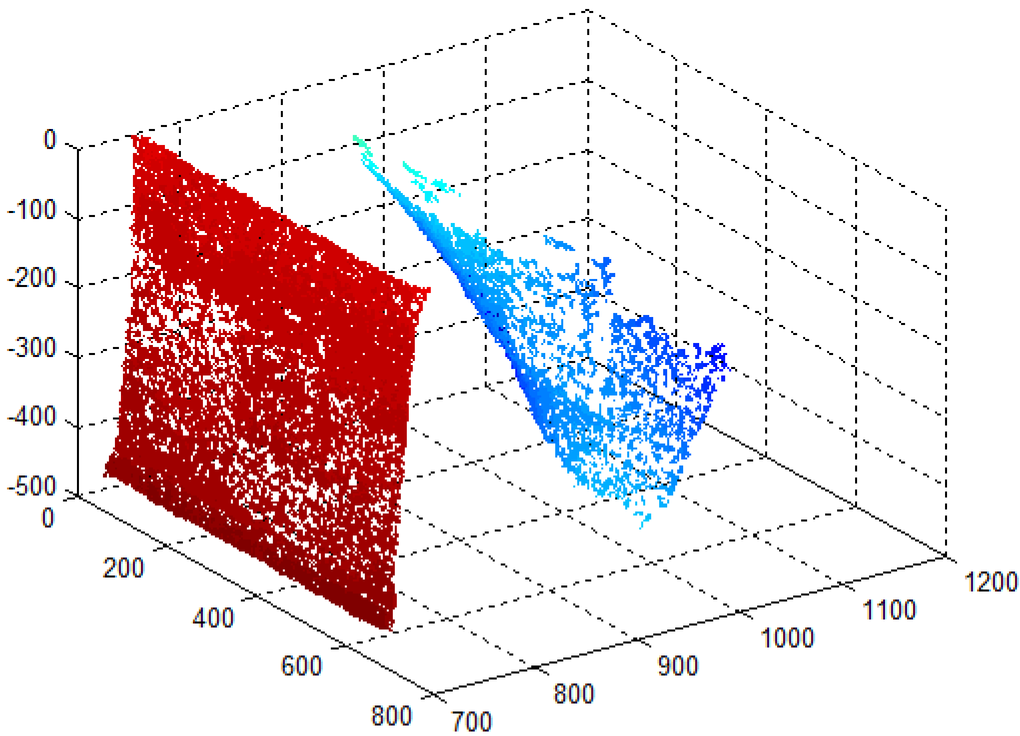


Figure 9: Depth image values for conflicts with calibration dots (same as Figure 8.2)

5.2 Further work

Even though two overlapping patterns are not fatal for the basic information in the depth image, this could very well be the case for conflicts including 3 or more Kinects. This has yet to be tested and documented.

Additionally, a piece of software capable of handling the obvious holes in the depth data as a result of the conflict would be advantageous to have for future developed software using the Kinect sensor. This could be a plugin which handles the potentially conflicted depth image from the Kinect, and passing it on in a smoothened version.

6. General considerations

While analyzing the Kinect for the primary aspects of interest, several additional details of relevance to the analysis have been uncovered. These topics are mentioned in this chapter.

6.1 Field of View

The VGA camera and IR camera are individual components placed 25mm apart, which leads to a slight difference in the area shown on the depth image and VGA image as expected. This however proves to be a minor detail compared to the difference in field of view.Through measurements with both VGA and IR cameras, the two fields of view are approximated as shown in the below Table 2.

	VGA	IR
Horizontal	~62°	~58°
Vertical	~48°	~44°
Diagonal	~72°	~69°

Table 2: Measured field of view for VGA and IR cameras

Compared to the official values provided by PrimeSense for their reference design, the field of view for the IR camera matches very well. The VGA camera has a slightly larger field of view, which makes it necessary to do scaling or cropping to make the two images better reflect the same environment details and positions.

6.2 Hardware

Figure 10: The Kinect sensor [4]

The Kinect is constructed to stand in front or on top of a television and thus has a single foot for stable positioning. On the earliest released European versions the connection between foot and sensor was silver colored, but is black as the rest of the case on current versions. Inside the foot is a joint which makes it possible to tilt the head of the Kinect. The tilt function is motorized, and can adjust the vertical direction of the sensor head approximately ±27°.

The several printed circuit boards inside the cabinet are cooled with a small fan, and equipped with an accelerometer for detection of the sensor head alignment. Along the bottom side of the sensor head is an array of multiple microphones, and on front (from left to right as seen on Figure 10) is the IR transmitter, multicolor LED, VGA camera and IR camera.

From current experience the connection to the foot and tilt mechanism is the weakest spot of the Kinect. After a short time of use, the sensor head positions itself slightly to the right, rotated in relation to its foot. This is no big issue for the intended use, but for use in mobile robotics, the way of mounting the sensor on a robot should definitely be considered. A much more reliable setup can be achieved by mounting the sensor without utilizing the foot. This way the build in accelerometer can also be used to detect the acceleration of the robot.

6.3 Power consumption

The Kinect is powered through either a special USB-like connection only available on the Xbox 360 "slim", or with the supplied 12V power adapter for use with any other standard USB connection.

Tests have shown that the power consumption of the external power source is approximately:

Power consumption (idle)	~3.3W
Power consumption (active)	~4.7W

The amount of power drawn from the USB2.0 connection has not been measured here. Information from PrimeSense does however imply that the core system is using only 2.25W, and that this is attainable through the USB2.0 connection alone.

6.4 Robustness

During continuous operation with the Linux drivers, the Kinect sometimes shut down entirely. Whether this is a hardware or software related issue is not. However, since the problem results in a complete shutdown of the sensor, it is plausible that the cause is either a hardware safety measure or a problem with the Linux USB driver.
The problem seems to be caused by moving the Kinect while it is running, which would be a major issue for use with mobile robots.

6.5 Outdoor use

Whereas the sensor seems to be almost immune to all indoor ambient light, as proclaimed by PrimeSense, it is definitely not suited for outdoor use. Tests have shown that no depth information is available for most outdoor scenarios.

As long as a certain part of the environment in view is not subjected to too much ambient light, the Kinect can also obtain reasonably detailed information on surfaces subjected to much ambient light. The reason might be the need for calibration. If one part of the depth image is calibrated, the method of detecting neighboring points has an origin to begin from.

The Kinect is thus not reliable for use outdoors, even though collection of successful readings is very likely possible in individual cases where walls or other smooth featurues are detectable in shadows.

Whether the Kinect provides reliable data in outdoor environments during the night, haven't been tested.

7. Conclusion

Through this project, a data sheet containing more detailed specifications on the precision of the Kinect than are available from official sources has been created. Furthermore, an evaluation of several important aspects when considering the use of Kinect for mobile robots has been conducted, making it possible to conclude that the Kinect should be considered as a very viable choice for use with mobile robots.

The results achieved match the few simple values provided by PrimeSense for their reference model, raising the expected reliability of the constructed data sheet.

Considering the results achieved and difficulties experienced, the Kinects applicability to mobile robots are evaluated in the following three categories:

Precision / resolution

As expected, the resolution is best at short distances and is reduced along with increasing distance. The relation is however predictable, making it easy to decide if the precision is sufficient for an intended use.

Within the distance interval 0.6m – 4.6m, the conducted test have shown that the Kinect delivers sufficiently detailed and precise data for use with mobile robots. It should however be noticed that the Kinect has a minimum range of at least 0.4m, making it a less viable choice for use without additional sensors.

Interference from another Kinect is acceptable to some extent, even though it has a significant negative impact on the details in acquired depth images.

Performance

The Kinect performs very well, with a full VGA sized depth image available at a rate of 30 frames per second. Processing of the data should definitely be kept internally in the software applications, as the depth images take up approximately 1.3MB space each, and thus takes up processing power if written to and read from a file.

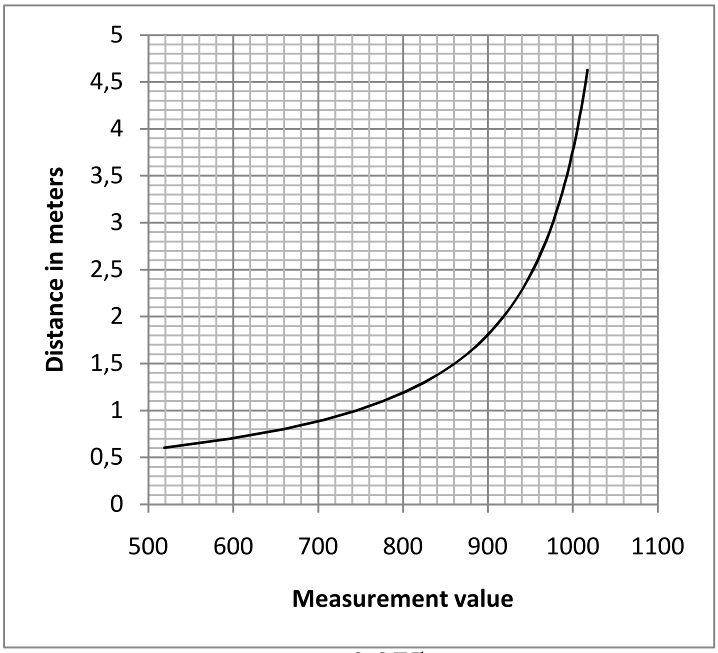
Reliability / robustness

The general physical construction of the Kinect seems suited for mobile use. The tilt ability and connection to the “foot” is however lacking in precision and robustness. Furthermore, an issue causing the Kinect to completely shut down seems to be caused when the sensor is moved around while running. This issue has to be identified and fixed before the Kinect can be considered a reliable data source for use with mobile robots.

Appendix A

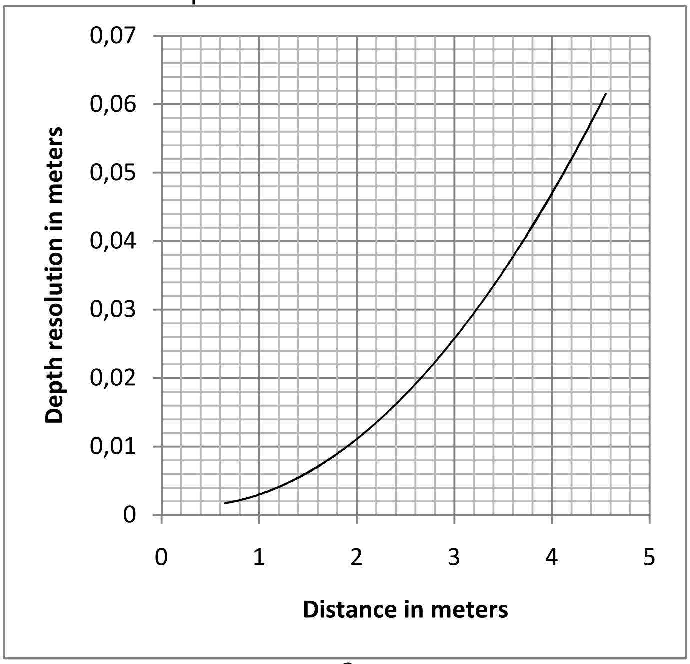
Kinect Data Sheet

Distance vs. 11-bit sensor value



$$y(x) = \frac{-0.075}{\tan(0.0002157x - 0.2356)} \quad [m]$$

Depth resolution vs. distance



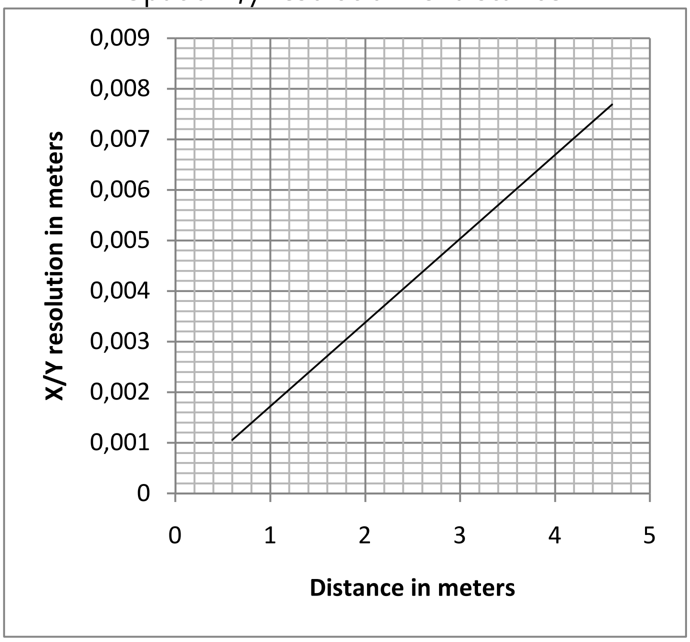
$$y(x) = 0.0033x^2 - 0.0017x \quad [m]$$

Depth image size	VGA(640x480)
Operation range	0.6m - 4.6m (at least)
Data interface	USB2.0
External power voltage	12V
Power consumption (idle) (external power source value)	~3.3W
Power consumption (active) (external power source value)	~4.7W

Field of view

	VGA	IR
Horizontal	~62°	~58°
Vertical	~48°	~44°
Diagonal	~72°	~69°

Spatial x/y resolution vs. distance



$$y(x) = 0.0017x \quad [m]$$

This datasheet contains values based on measurements, and are subject to possible variations for use with other Kinects than those used in this specific case.

Appendix B

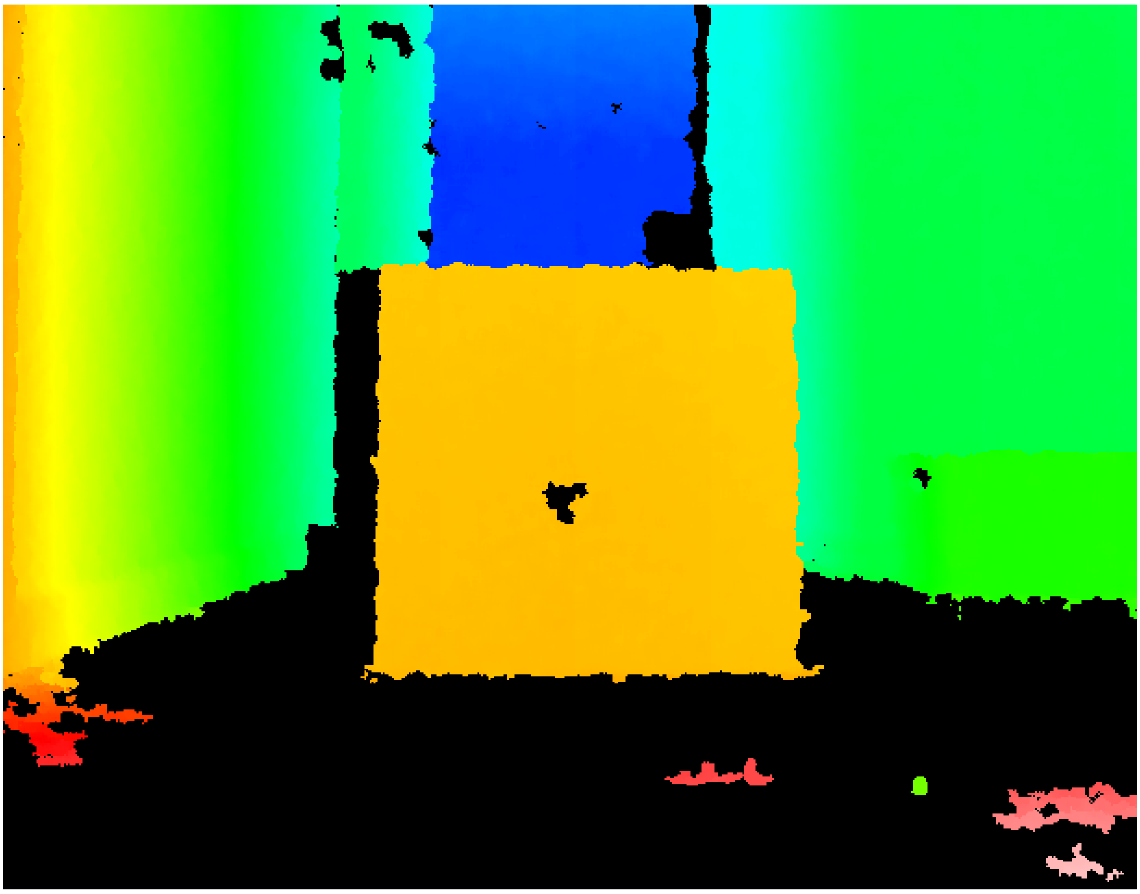


Figure 11: The depth scan taken with the setup shown in Figure 2.

Appendix C

Measurement and calculation table for spatial x/y resolution.

Dist.	Horizontal pix. mean	Vertical pix. mean	Horizontal res. [m]	Vertical res. [m]	Mean res. [m]
0.6	374.60	362.76	0.0010	0.0010	0.001044
0.7	325.27	314.44	0.0012	0.0012	0.001204
0.8	283.64	274.43	0.0014	0.0014	0.001380
0.9	253.12	244.35	0.0015	0.0015	0.001548
1.0	229.13	220.77	0.0017	0.0017	0.001712
1.1	208.07	200.91	0.0019	0.0019	0.001883
1.2	191.27	184.29	0.0020	0.0021	0.002050
1.3	176.10	170.75	0.0022	0.0022	0.002220
1.4	164.04	158.65	0.0024	0.0024	0.002386
1.5	152.85	148.68	0.0026	0.0025	0.002553
1.6	144.18	138.89	0.0027	0.0027	0.002720
1.7	136.58	130.64	0.0029	0.0029	0.002882
1.8	129.49	122.97	0.0030	0.0031	0.003051
1.9	121.70	117.24	0.0032	0.0032	0.003223
2.0	116.42	111.44	0.0034	0.0034	0.003380
2.1	109.89	106.11	0.0036	0.0036	0.003565
2.2	104.86	101.52	0.0037	0.0037	0.003731
2.3	101.06	96.67	0.0039	0.0039	0.003895
2.4	96.76	93.71	0.0041	0.0040	0.004042
2.5	92.01	90.04	0.0043	0.0042	0.004229
2.6	89.13	85.58	0.0044	0.0044	0.004407
2.7	86.33	83.57	0.0045	0.0045	0.004532
2.8	83.43	79.33	0.0047	0.0048	0.004732
2.9	80.90	77.28	0.0048	0.0049	0.004868
3.0	77.39	76.91	0.0051	0.0049	0.004990
3.1	75.37	71.74	0.0052	0.0053	0.005235
3.2	72.88	70.11	0.0054	0.0054	0.005385
3.3	70.67	67.22	0.0055	0.0056	0.005585
3.4	68.70	66.34	0.0057	0.0057	0.005702
3.5	66.86	64.57	0.0059	0.0059	0.005859
3.6	65.42	60.89	0.0060	0.0062	0.006100
3.7	64.04	60.46	0.0061	0.0063	0.006187
3.8	61.68	59.12	0.0064	0.0064	0.006375
3.9	61.08	57.78	0.0064	0.0065	0.006480
4.0	60.22	56.18	0.0065	0.0067	0.006619
4.1	58.06	55.32	0.0068	0.0068	0.006792
4.2	56.66	53.52	0.0069	0.0071	0.006991
4.3	55.02	52.14	0.0071	0.0072	0.007187
4.4	53.78	50.46	0.0073	0.0075	0.007390
4.5	52.79	49.69	0.0074	0.0076	0.007516
4.6	51.14	48.65	0.0077	0.0078	0.007718

Table 3: Measurement and calculation table for spatial x/y resolution.

Appendix D

Calculated depth resolution values.

Distance Interval end value	Depth Z Res. [m]
0.6	-
0.7	0.00130
0.8	0.00157
0.9	0.00211
1.0	0.00261
1.1	0.00316
1.2	0.00384
1.3	0.00447
1.4	0.00529
1.5	0.00607
1.6	0.00695
1.7	0.00763
1.8	0.00871
1.9	0.01006
2.0	0.01068
2.1	0.01210
2.2	0.01402
2.3	0.01428
2.4	0.01522
2.5	0.01736
2.6	0.01841
2.7	0.01941
2.8	0.02336
2.9	0.02212
3.0	0.02403
3.1	0.02717
3.2	0.02739
3.3	0.02949
3.4	0.03205
3.5	0.03690
3.6	0.03236
3.7	0.03984
3.8	0.04386
3.9	0.03802
4.0	0.04950
4.1	0.04201
4.2	0.06135
4.3	0.04405
4.4	0.06578
4.5	0.05319
4.6	0.06289

Table 4: Calculated depth resolution values for the 0.1m up to the distance value indicated

Appendix E

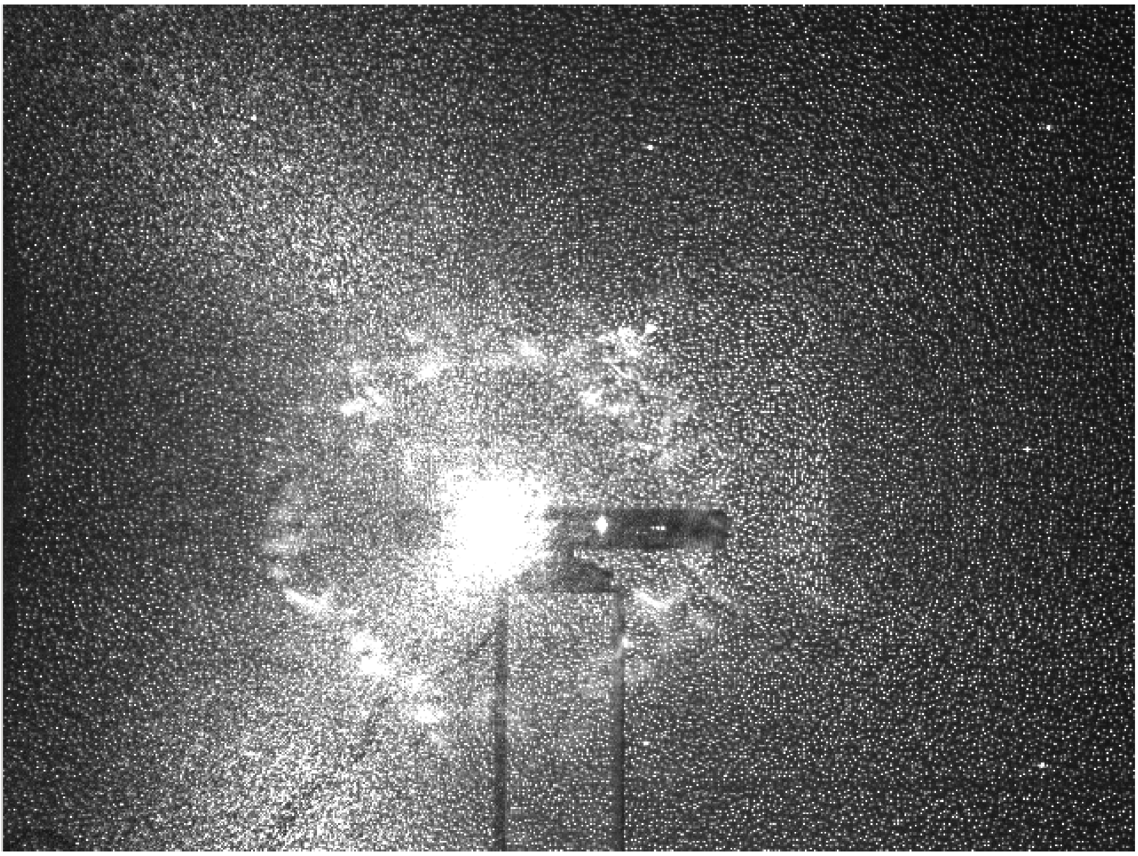


Figure 12: A Kinect sensor blinding the one used to take this picture

References

[1] PrimeSense website: http://www.primesense.com

[2] Mobotware website: http://timmy.elektro.dtu.dk/rse/wiki/index.php/Main_Page#Mobotware

[3] OpenKinect website: http://openkinect.org

[4] ifixit teardown: http://www.ifixit.com/Teardown/Microsoft-Kinect-Teardown/4066/1

[5] Futurepicture blog: http://www.futurepicture.org/?p=129

CD Contents

The CD contains the depth data images used in this report, as well as the MATLAB script files used to process them. Images and video of a disassembled Kinect is also available, along with pdf's of this report and the patent description for Light Coding.

Folders on the CD:

Spatial_and_depth_resolution

Contains all measurement data for the 40 measurements, along with MATLAB script for data processing, and excel sheet for plots.

2xKinect_conflicts

Contains measurement data for the experiments with several Kinects

aukinect

Contains the modified Kinect plugin for Mobotware used for data collection. The command "Kinect savedepth" saves the current view to a 11-bit resolution depth image on a specific drive location.

M**edia**

Contains Images and video of a Kinect teardown from "ifixit", along with images of the projected IR pattern on a wall.

pdf

Contains a pdf version of this report, the reference design specifications from PrimeSense, as well as a patent on the idea behind Light Coding.

Treat_data.m – MATLAB code

```
clear all;

%run this script in the data directory, and uncomment the distance to
%analyze.

%xmin=120; xmax=700; ymin=-700; ymax=700; min=511; max=529; file = load('60cm');  vresminx=200; vresmaxx=500; hresminy=50; hresmaxy=400;
xmin=0; xmax=510; ymin=-700; ymax=700; min=588; max=605; file = load('70cm');  vresminx=200; vresmaxx=500; hresminy=100; hresmaxy=350;
%xmin=150; xmax=700; ymin=-700; ymax=700; min=655; max=665; file = load('80cm');  vresminx=200; vresmaxx=450; hresminy=100; hresmaxy=350;
%xmin=150; xmax=500; ymin=0; ymax=350; min=701; max=715; file = load('90cm');  vresminx=200; vresmaxx=440; hresminy=120; hresmaxy=320;
%xmin=200; xmax=700; ymin=-700; ymax=700; min=742; max=749; file = load('100cm');  vresminx=230; vresmaxx=430; hresminy=130; hresmaxy=320;
%xmin=200; xmax=500; ymin=-700; ymax=700; min=774; max=780; file = load('110cm');  vresminx=250; vresmaxx=420; hresminy=140; hresmaxy=320;
%xmin=200; xmax=500; ymin=-700; ymax=700; min=800; max=806; file = load('120cm');  vresminx=250; vresmaxx=410; hresminy=150; hresmaxy=310;
%xmin=200; xmax=500; ymin=-700; ymax=700; min=822; max=828; file = load('130cm');  vresminx=250; vresmaxx=410; hresminy=150; hresmaxy=300;
%xmin=200; xmax=700; ymin=-700; ymax=700; min=841; max=847; file = load('140cm');  vresminx=250; vresmaxx=400; hresminy=160; hresmaxy=300;
%xmin=200; xmax=500; ymin=-700; ymax=700; min=858; max=863; file = load('150cm');  vresminx=260; vresmaxx=390; hresminy=160; hresmaxy=290;
%xmin=200; xmax=700; ymin=-700; ymax=700; min=872; max=879; file = load('160cm');  vresminx=260; vresmaxx=390; hresminy=170; hresmaxy=290;
%xmin=200; xmax=500; ymin=-700; ymax=700; min=885; max=890; file = load('170cm');  vresminx=270; vresmaxx=380; hresminy=170; hresmaxy=280;
%xmin=250; xmax=450; ymin=-700; ymax=700; min=896; max=902; file = load('180cm');  vresminx=280; vresmaxx=380; hresminy=170; hresmaxy=280;
%xmin=250; xmax=450; ymin=-700; ymax=700; min=907; max=912; file = load('190cm');  vresminx=270; vresmaxx=380; hresminy=180; hresmaxy=280;
%xmin=250; xmax=450; ymin=-700; ymax=700; min=916; max=921; file = load('200cm');  vresminx=270; vresmaxx=380; hresminy=180; hresmaxy=280;
%xmin=250; xmax=450; ymin=-700; ymax=700; min=924; max=930; file = load('210cm');  vresminx=280; vresmaxx=370; hresminy=180; hresmaxy=280;
%xmin=250; xmax=450; ymin=-700; ymax=700; min=932; max=936; file = load('220cm');  vresminx=280; vresmaxx=370; hresminy=180; hresmaxy=270;
%xmin=250; xmax=400; ymin=-700; ymax=700; min=939; max=943; file = load('230cm');  vresminx=280; vresmaxx=370; hresminy=190; hresmaxy=270;
%xmin=250; xmax=400; ymin=-700; ymax=700; min=945; max=950; file = load('240cm');  vresminx=280; vresmaxx=360; hresminy=190; hresmaxy=270;
%xmin=250; xmax=400; ymin=-700; ymax=700; min=951; max=956; file = load('250cm');  vresminx=280; vresmaxx=360; hresminy=190; hresmaxy=270;
%xmin=250; xmax=400; ymin=-700; ymax=700; min=957; max=962; file = load('260cm');  vresminx=280; vresmaxx=360; hresminy=190; hresmaxy=265;
%xmin=250; xmax=400; ymin=-700; ymax=700; min=961; max=966; file = load('270cm');  vresminx=290; vresmaxx=360; hresminy=190; hresmaxy=265;
%xmin=250; xmax=400; ymin=-700; ymax=700; min=966; max=970; file = load('280cm');  vresminx=280; vresmaxx=360; hresminy=190; hresmaxy=265;
%xmin=250; xmax=380; ymin=-700; ymax=700; min=971; max=975; file = load('290cm');  vresminx=285; vresmaxx=360; hresminy=195; hresmaxy=265;
%xmin=250; xmax=380; ymin=-700; ymax=700; min=975; max=979; file = load('300cm');  vresminx=290; vresmaxx=355; hresminy=190; hresmaxy=255;
%xmin=250; xmax=380; ymin=-700; ymax=700; min=979; max=983; file = load('310cm');  vresminx=290; vresmaxx=355; hresminy=190; hresmaxy=255;
%xmin=250; xmax=380; ymin=-700; ymax=700; min=982; max=986; file = load('320cm');  vresminx=290; vresmaxx=355; hresminy=190; hresmaxy=255;
%xmin=250; xmax=380; ymin=-700; ymax=700; min=986; max=990; file = load('330cm');  vresminx=290; vresmaxx=355; hresminy=195; hresmaxy=255;
%xmin=250; xmax=380; ymin=-700; ymax=700; min=989; max=993; file = load('340cm');  vresminx=290; vresmaxx=355; hresminy=195; hresmaxy=255;
%xmin=0; xmax=700; ymin=-700; ymax=700; min=992; max=996; file = load('350cm');  vresminx=290; vresmaxx=350; hresminy=195; hresmaxy=250;
%xmin=0; xmax=700; ymin=-700; ymax=700; min=994; max=1000; file = load('360cm');  vresminx=295; vresmaxx=350; hresminy=200; hresmaxy=255;
%xmin=0; xmax=700; ymin=-700; ymax=700; min=997; max=1001; file = load('370cm');  vresminx=295; vresmaxx=350; hresminy=205; hresmaxy=255;
%xmin=0; xmax=700; ymin=-700; ymax=300; min=999; max=1003; file = load('380cm');  vresminx=295; vresmaxx=345; hresminy=205; hresmaxy=255;
%xmin=0; xmax=700; ymin=-700; ymax=700; min=1001; max=1007; file = load('390cm');  vresminx=295; vresmaxx=345; hresminy=205; hresmaxy=255;
%xmin=0; xmax=700; ymin=-700; ymax=700; min=1004; max=1009; file = load('400cm');  vresminx=295; vresmaxx=345; hresminy=205; hresmaxy=255;
%xmin=0; xmax=700; ymin=-700; ymax=700; min=1006; max=1011; file = load('410cm');  vresminx=295; vresmaxx=345; hresminy=205; hresmaxy=255;
%xmin=0; xmax=700; ymin=-700; ymax=700; min=1008; max=1013; file = load('420cm');  vresminx=295; vresmaxx=345; hresminy=205; hresmaxy=255;
%xmin=290; xmax=700; ymin=-700; ymax=700; min=1011; max=1015; file = load('430cm');  vresminx=295; vresmaxx=345; hresminy=205; hresmaxy=254;
%xmin=280; xmax=700; ymin=-700; ymax=700; min=1012; max=1017; file = load('440cm');  vresminx=295; vresmaxx=345; hresminy=205; hresmaxy=250;
%xmin=280; xmax=700; ymin=-700; ymax=700; min=1013; max=1019; file = load('450cm');  vresminx=297; vresmaxx=345; hresminy=207; hresmaxy=250;
%xmin=280; xmax=700; ymin=-700; ymax=300; min=1015; max=1021; file = load('460cm');  vresminx=292; vresmaxx=340; hresminy=208; hresmaxy=252;

%load data
i = 1;
for i=1:480
A(i,:) = file(i,:);
end

%divide with this for lower resolution
res=1;

%3D plot
infPoint = 0;
for i=1:res:480
        for j=1:res:640
                if (A(i,j) <= min || A(i,j) >= max || i < ymin || i > ymax || j < xmin || j > xmax)
                    infPoint = infPoint+1;
                end
        end
end

poi = (480/res)*(640/res)-infPoint;
PM = zeros(3,poi);

verticalminmax = zeros(vresmaxx-vresminx,2);
verticalminmax(:,1)=1000;
horisontalminmax = zeros(hresmaxy-hresminy,2);
horisontalminmax(:,1)=1000;

totalval=0;
count=1;
previ = 1;
```

```
for i=1:res:480
    if (i > ymin && i < ymax)
        for j=1:res:640
            if (j > xmin && j < xmax)
                if (A(i,j) >= min && A(i,j) <= max)
                    PM(1,count)=j;
                    PM(2,count)=i;
                    PM(3,count)=A(i,j);
                    count=count+1;
                    totalval = totalval + A(i,j);

                if(i > hresminy && i <= hresmaxy)
                    if (j < horisontalminmax(i-hresminy,1))
                        horisontalminmax(i-hresminy,1) = j;
                    end
                    if (j > horisontalminmax(i-hresminy,2))
                        horisontalminmax(i-hresminy,2) = j;
                    end
                end

                if(j > vresminx && j <= vresmaxx)
                    if (i < verticalminmax(j-vresminx,1))
                        verticalminmax(j-vresminx,1) = i;
                    end
                    if (i > verticalminmax(j-vresminx,2))
                        verticalminmax(j-vresminx,2) = i;
                    end
                end

                end

            end
        end
    end
    CompletionInPercent = count/(((640/res)*(480/res))-infPoint)*100
end
meanDepthVal = totalval/count

%horisontal resolution
htotal = 0;
for (i=1:hresmaxy-hresminy)
    htotal = htotal + horisontalminmax(i,2) - horisontalminmax(i,1);
end
hResMean = htotal/(hresmaxy-hresminy)

%vertical resolution
vtotal = 0;
for (i=1:vresmaxx-vresminx)
    vtotal = vtotal + verticalminmax(i,2) - verticalminmax(i,1);
end
vResMean = vtotal/(vresmaxx-vresminx)

figure(3)
scatter3(PM(1,:),PM(3,:),-PM(2,:),10,-PM(3,:),'filled'); %'filled'
%view(25,25);
colorbar;
view(80,0);
axis off;
grid off;
figure(4)
scatter3(PM(1,:),PM(3,:),-PM(2,:),10,-PM(3,:),'filled'); %'filled'
%view(25,25);
colorbar;
view(0,0);
%axis off;
%grid off;
```