3D Reconstruction Using Standard Stereo

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Introduction

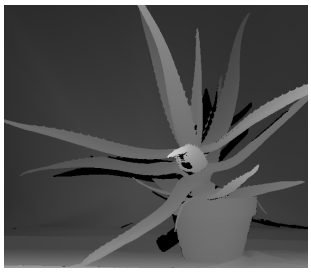
The algorithms employed use stereo matching techniques in order to create a point cloud from the given stereo images. The images are made with a standard stereo setup, meaning that the optical axes are parallel to eachother. This makes the 3D reconstruction easier as we don't have to estimate the transformation between the two image planes.

The images are from the Middlebury dataset. An example is shown below:

The aim was to create a 3-dimensional reconstruction of the scene in the form of a point cloud, using multiple algorithms:

1. Naive approach
2. Dynamic programming

One of the most important elements of the reconstruction is the disparity image, that refers to the apparent difference of pixels as seen in the two images. This information is known for ecery corresponding pixel in both of the images, hence the reconstruction is possible. The ground truth disparities are available as well. An example for ground truth disparity:



The measure of correspondence can be measured between the disparity image calculated using the algorithms and the ground truth. This will be a crucial aspect of our further analysis. The similarity metrics that were measured are:

1. SSD/MSD - Sum of Squared Differences / Mean Squared Difference

$$SSD(d_1, d_2) = \sum\sum(f(x+i, y+j) - g(x+i-d_1, y+j-d_2))$$

2. SSIM - Structural Similarity Index

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

3. NCC - Normalized Cross Covariance

$$NCC(x, y) = \frac{1}{n}\sum\frac{(f(x, y) - \mu_f)(g(x, y) - \mu_g)}{\sigma_f\sigma_g}$$

In this study the following images have been processed (each from the Middlebury dataset):

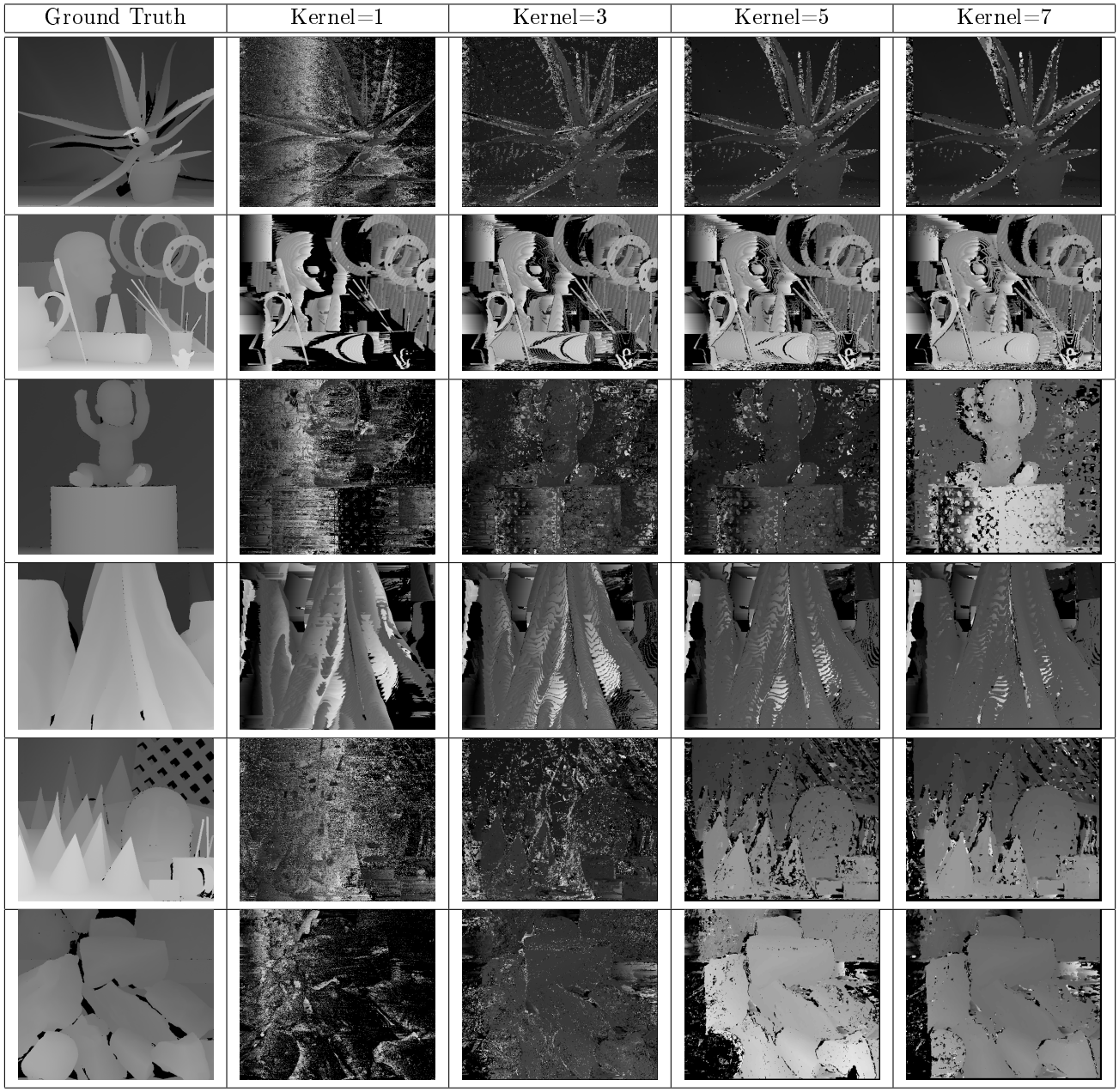
1. Aloe
2. Art
3. Baby
4. Cloth
5. Cones
6. Rocks

If the point positions are calculated it is also possible to assign the normal vectors to each of the points, creating an oriented point cloud. Where each normal vector denotes the orientation of the triangle defined by the two closest point to a given point.

Disparity Maps

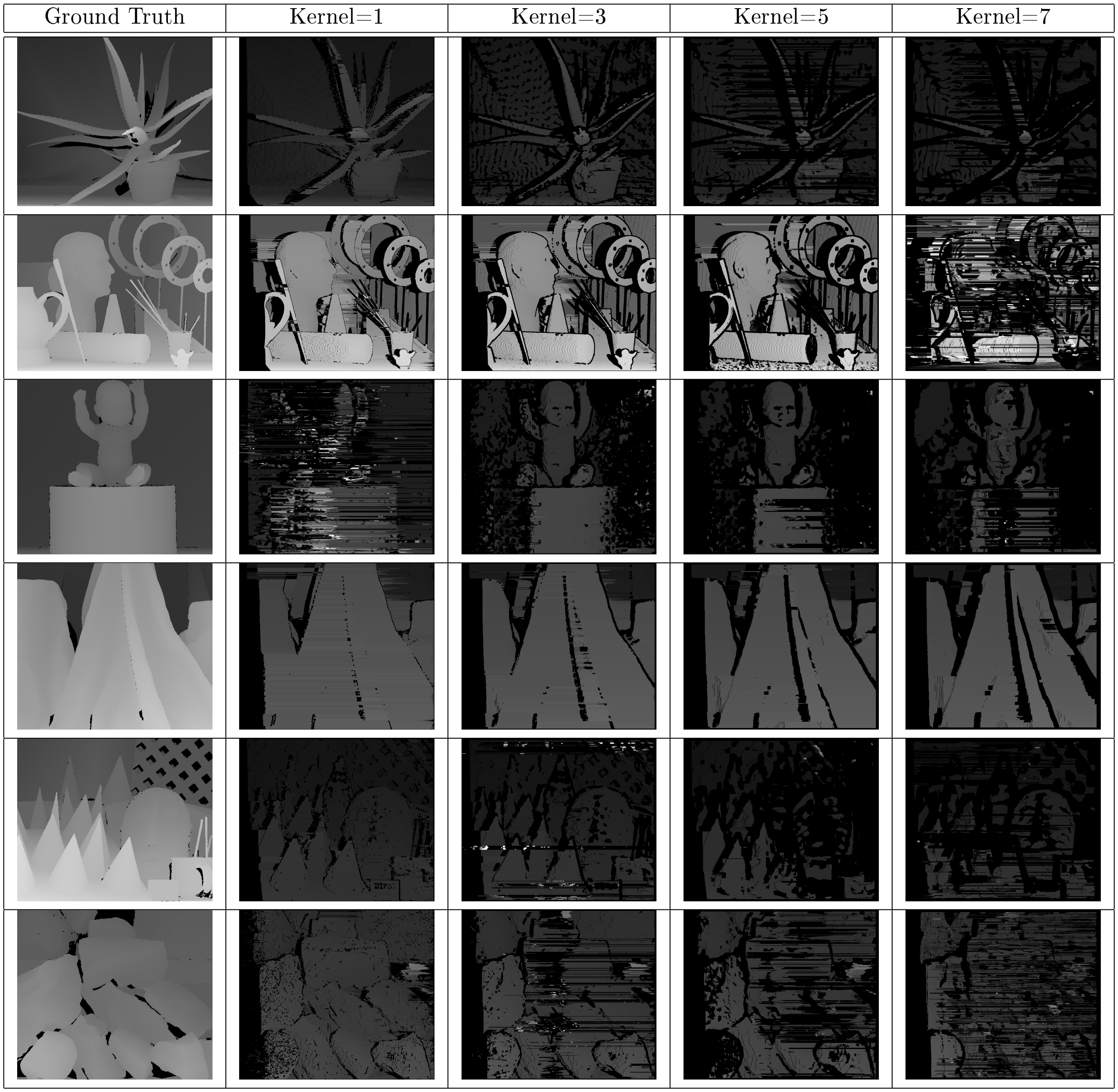
Below is a comparison of how the algorithm performed on multiple window sizes and approach of computation compared to the ground truth disparities.

Naive Approach



Dynamic Programming

Note: not all images use the same λ parameter.

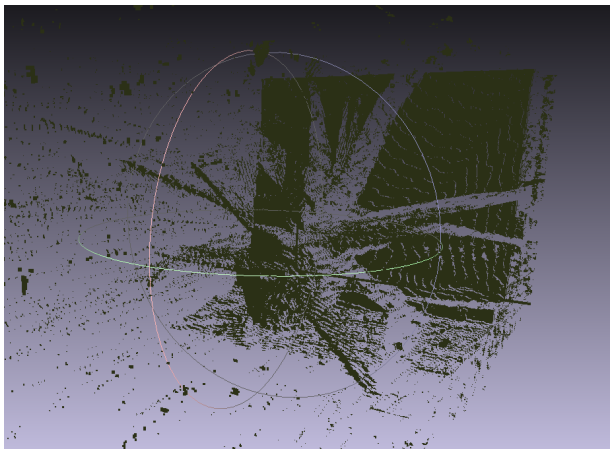


Point Clouds

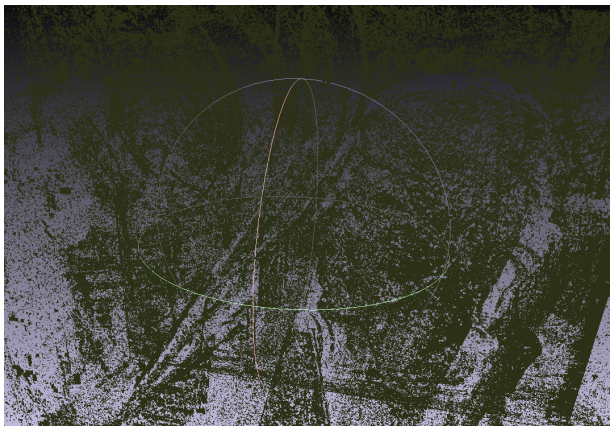
The following section will feature snapshots of (not necessarily the best) point clouds for each image and each computation approach. The kernel size and λ is again not the same for all images as these parameters behave very differently in different environments.

Naive

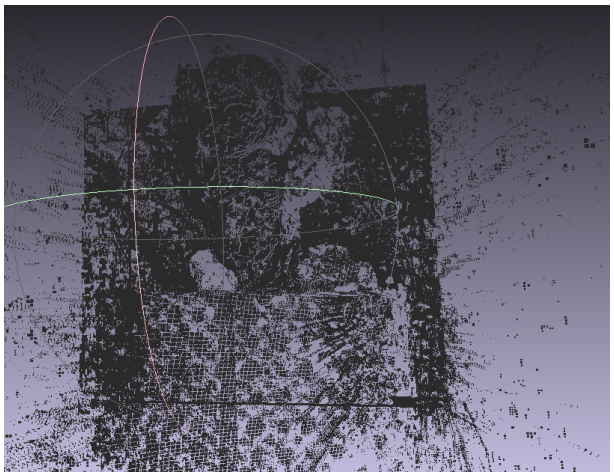
Aloe



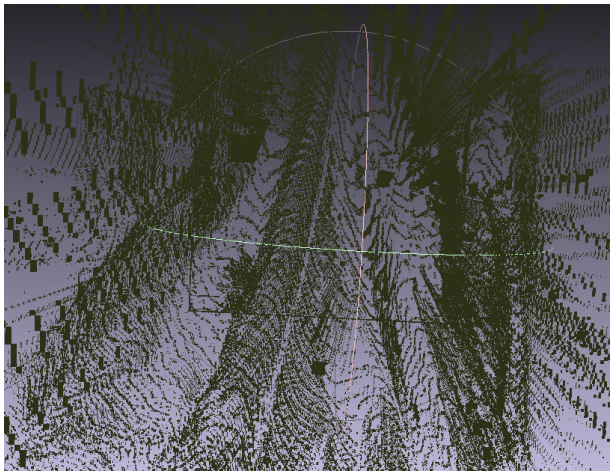
Art



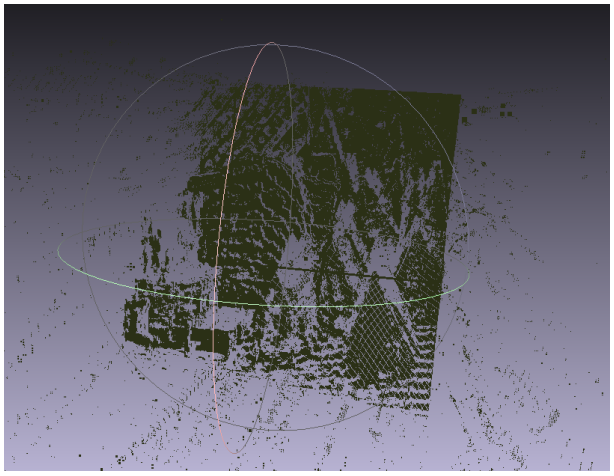
Baby



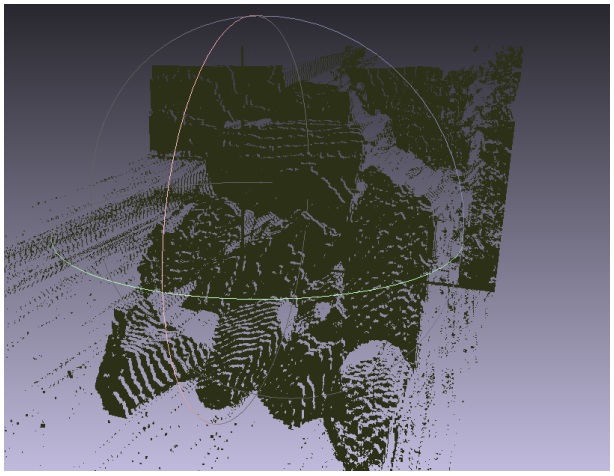
Cloth



Cones

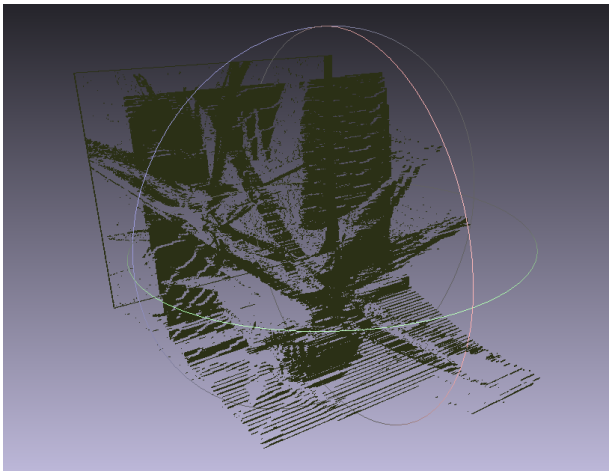


Rocks

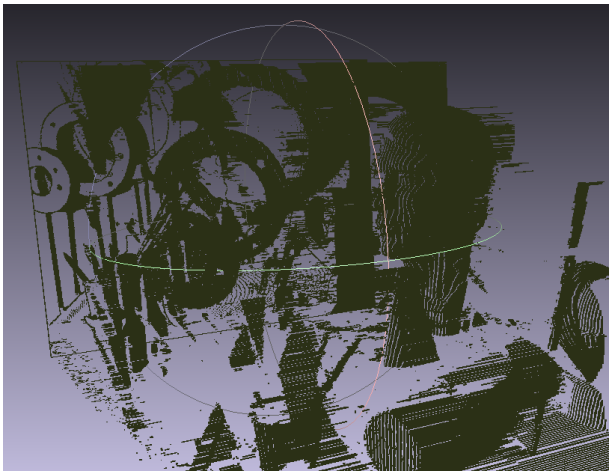


Dynamic

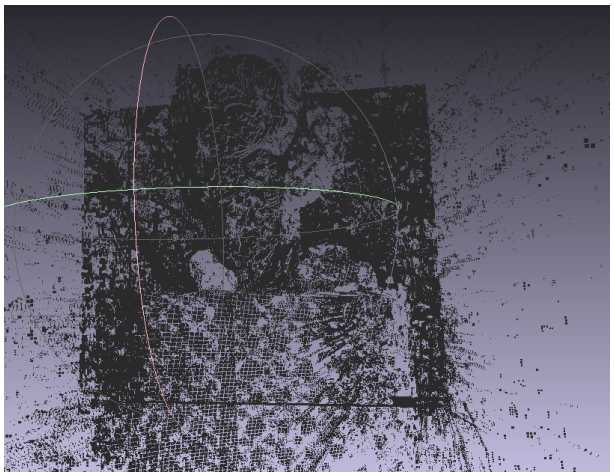
Aloe



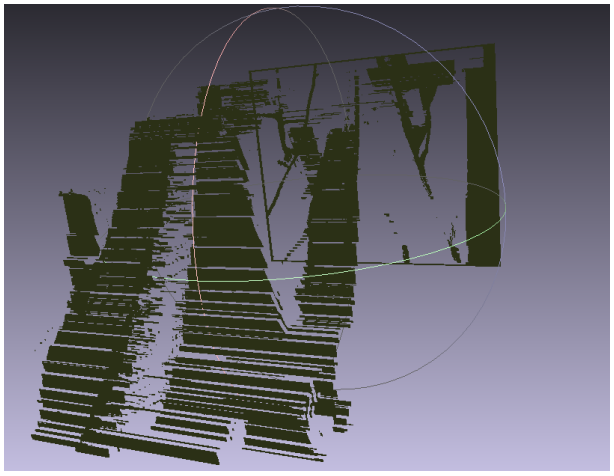
Art



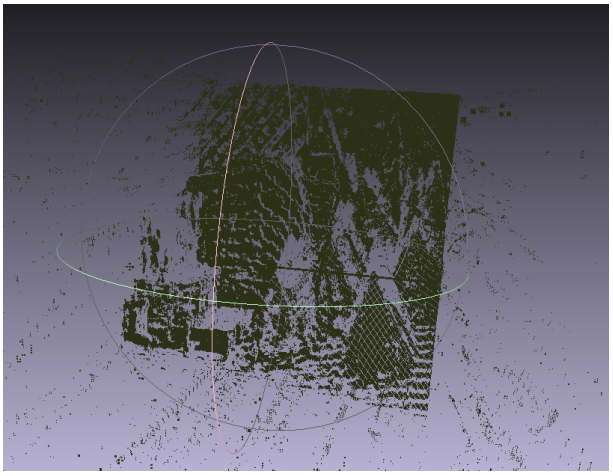
Baby



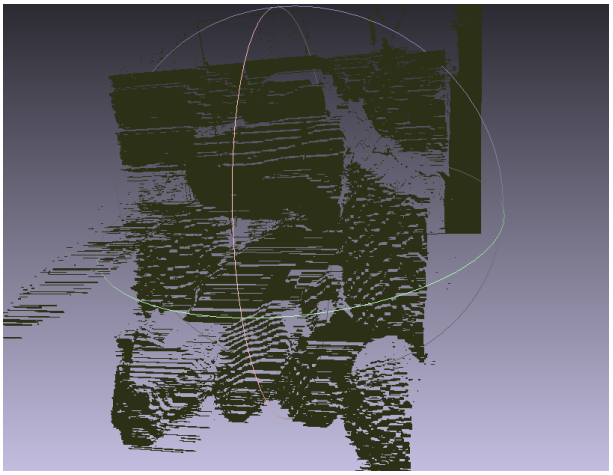
Cloth



Cones

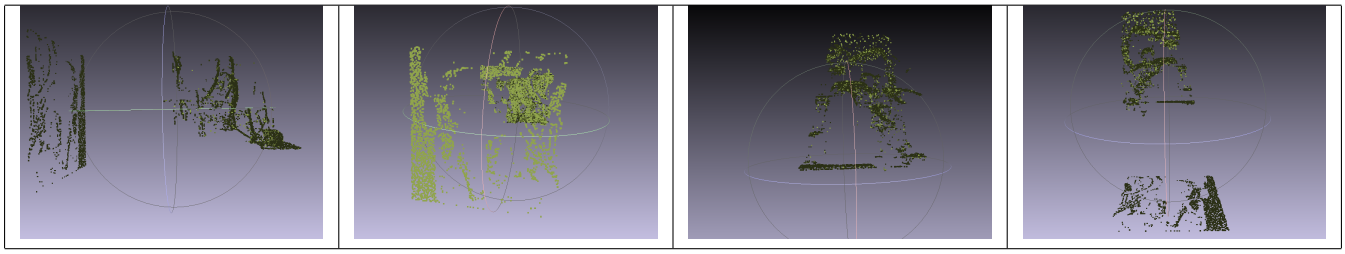


Rocks



Oriented

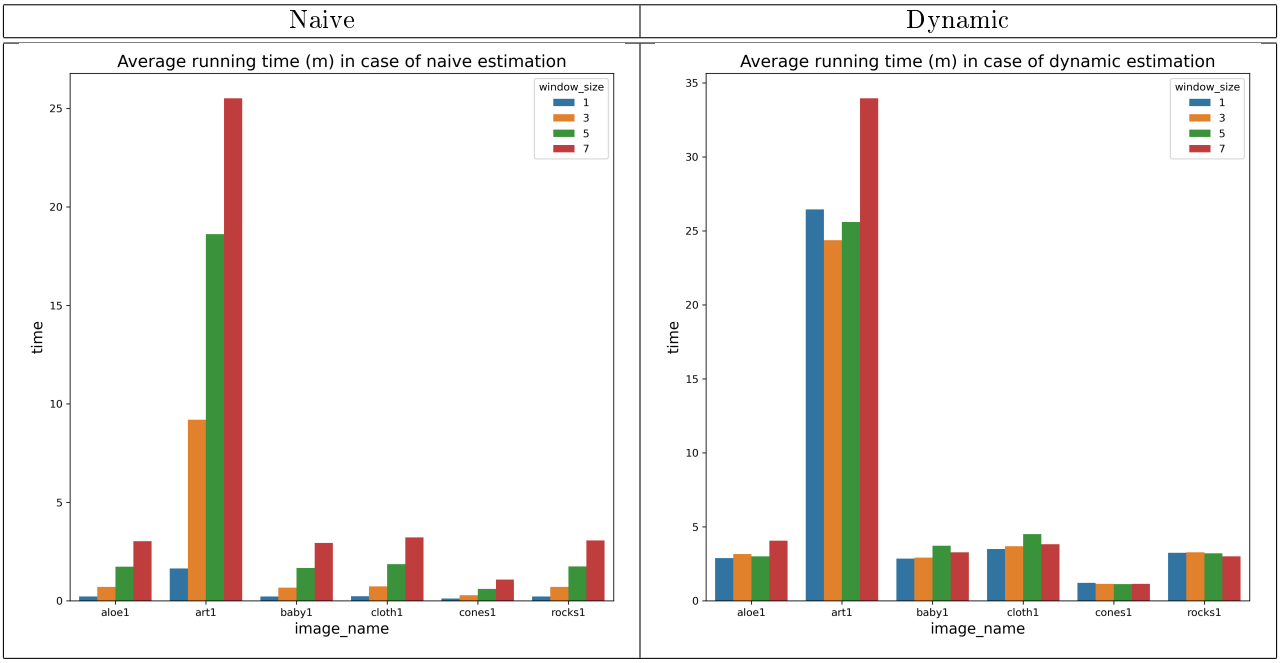
This part will feature a short demonstration of a single point cloud that has been rendered into an oriented cloud. Other images are not shown as it would be redundant. The points have been subsampled in case of all the images to contain approximately 20000 points. The way oriented clouds appear in Meshlab is that whenever a normal vector is facing the viewer the mesh point will turn green. So green points in a point cloud belong to a plane that is perpendicular to the viewing axis of the human viewer. The oriented cloud can be seen from different viewing angles.



The *oriented* folder contains several point clouds rendered into oriented point clouds.

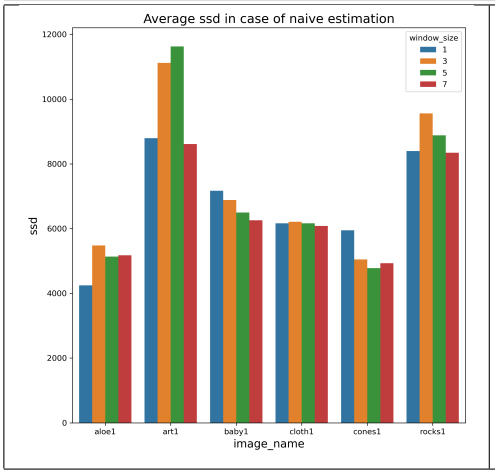
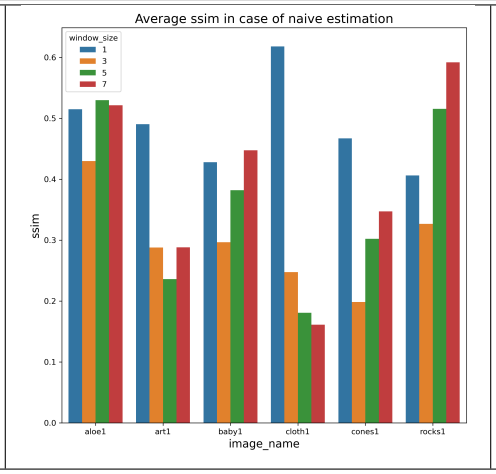
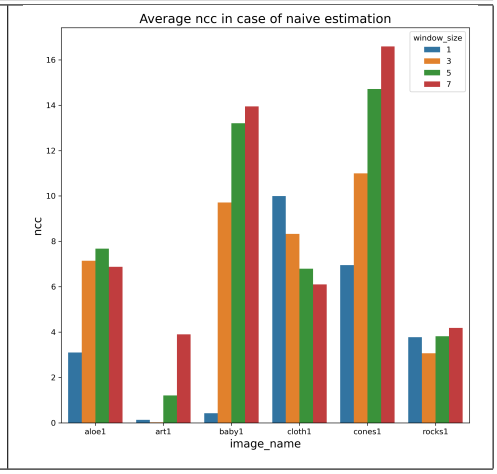
Statistical analysis

Time to finish / kernel size

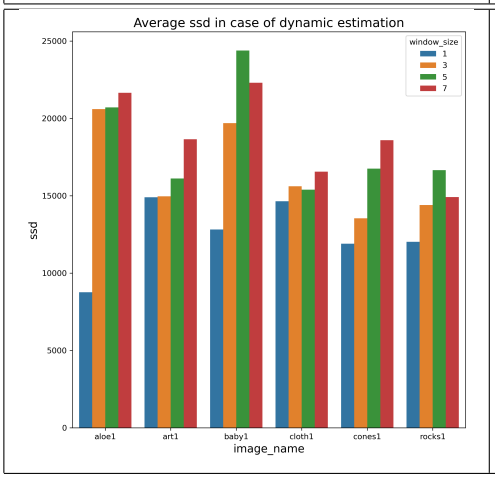
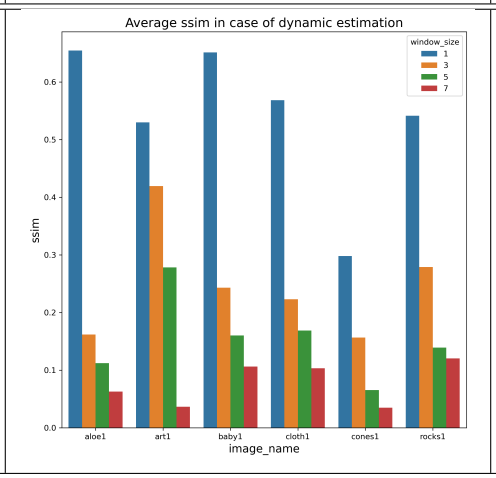
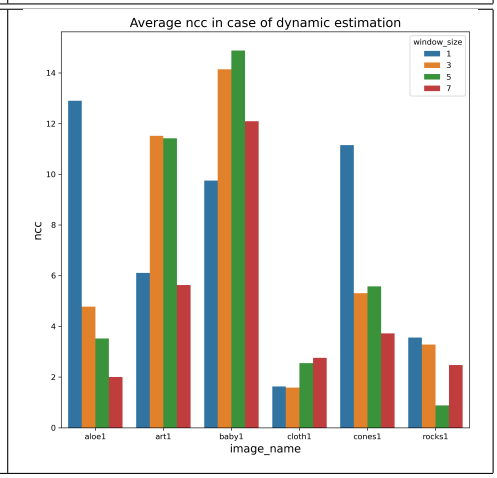


Average of similarity measure / image

Naive

SSD	SSIM	NCC
		

Dynamic

SSD	SSIM	NCC
		

Optimal parameters

The following section gives a brief overview of the best performin parameters such as λ,window size and dmin according to each similarity measure. A lot of times the best parameters coincide.

SSD

name	image_name	lambda	window_size	dmin	time	ssd
naive	cones1	-	7	230	1.0666666666666667	3346.91
dynamic	cones1	100	1	230	1.2166666666666666	8398.86
naive	art1	-	5	200	26.15	8592.55
dynamic	art1	4	1	230	28.866666666666667	14329.9
naive	aloe1	-	1	200	0.21666666666666667	4247.03
dynamic	aloe1	50	1	270	2.8833333333333333	8755.33
naive	baby1	-	1	300	0.21666666666666667	5076.57
dynamic	baby1	100	1	300	2.85	12811.1
naive	cloth1	-	7	260	3.3333333333333335	6084.61
dynamic	cloth1	150	1	260	3.066666666666667	13928.6
naive	rocks1	-	7	274	3.0166666666666666	6623.38
dynamic	rocks1	100	1	274	3.3333333333333335	10221.8

SSIM

name	image_name	lambda	window_size	dmin	time	ssim
naive	cones1	-	1	230	0.08333333333333333	0.544374
dynamic	cones1	100	1	230	1.2166666666666666	0.39646
naive	art1	-	1	230	1.6166666666666667	0.490281
dynamic	art1	4	1	230	28.866666666666667	0.605166
naive	aloe1	-	5	270	1.75	0.529653
dynamic	aloe1	50	1	270	2.8833333333333333	0.654334
naive	baby1	-	1	300	0.21666666666666667	0.513868
dynamic	baby1	100	1	300	2.85	0.65117
naive	cloth1	-	1	260	0.23333333333333334	0.617756
dynamic	cloth1	150	1	260	3.066666666666667	0.585746
naive	rocks1	-	7	274	3.0166666666666666	0.654456
dynamic	rocks1	50	1	274	3.2	0.665185

NCC

name	image_name	lambda	window_size	dmin	time	ncc
naive	cones1	-	7	230	1.0666666666666667	23.2076
dynamic	cones1	50	1	230	1.15	14.7494
naive	art1	-	7	200	25.283333333333335	3.89721
dynamic	art1	4	3	200	24.366666666666667	11.5145
naive	aloe1	-	5	270	1.75	7.67926
dynamic	aloe1	50	1	270	2.8833333333333333	12.8984
naive	baby1	-	7	300	2.9166666666666665	24.2819
dynamic	baby1	50	3	300	3.25	18.7203
naive	cloth1	-	1	260	0.23333333333333334	9.99904
dynamic	cloth1	200	1	260	3.433333333333333	3.59941
naive	rocks1	-	7	274	3.0166666666666666	6.46472
dynamic	rocks1	200	3	274	3.15	5.33114