ITSUMEIKAN UNIV.
Computer Graphics Lab 1

High-quality Visualization of Large-Scale Noisy Point Clouds Acquired by 3D Scanning

Tomomasa Uchida[1,*], Kyoko Hasegawa[2], Liang Li[2], Motoaki Adachi[3], Satoshi Tanaka[2]

[1]Graduate School of Information Science & Engineering, Ritsumeikan University, Japan
[2]College of Information Science & Engineering, Ritsumeikan University, Japan
[3]Shrewd Design Co. Ltd, Japan

Background（1/3）

- **Development of 3D scanning technology**
  - It has become possible to record real 3D objects that **describe very complex 3D shapes**
  - The acquired point clouds have **10^7～10^9 3D points**
  - **Digital archiving** is actively done

Target object

Laser scanning

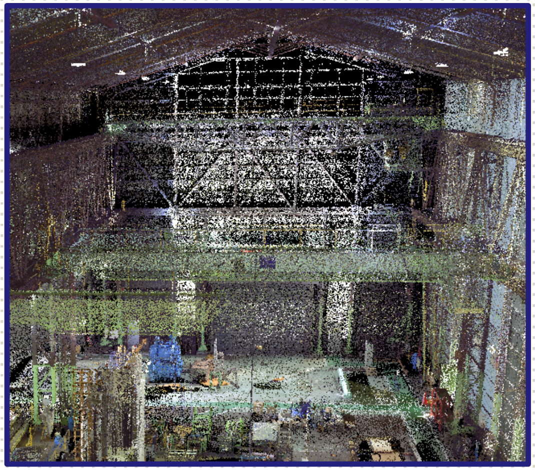
3D point cloud

Background（2/3）

- **The difficulty in using laser-scanned point clouds**
  - Measurement noise often occurs
    → To utilize acquired data, **noise reduction is necessary**

Trees with leaves

Glass windows



Powder dust

Laser light scattering → Position misdetection → Noise occurs

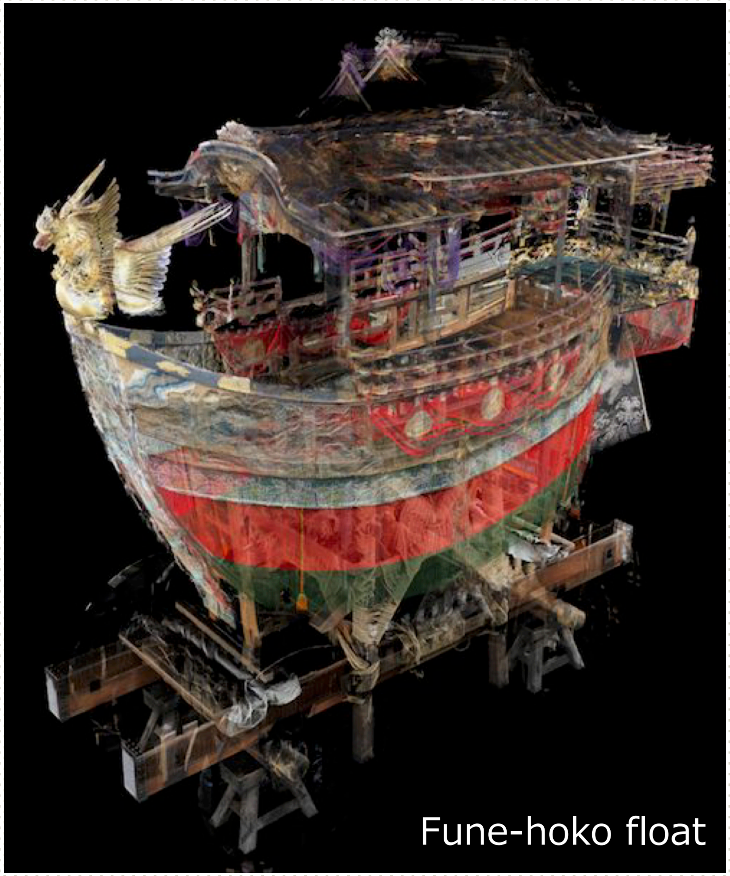
Background（3/3）

Stochastic Point-Based Rendering（SPBR）

- A novel method of transparent visualization without sorting
- SPBR has **the effect of making target objects transparent** through the rendering process

Hypothesis

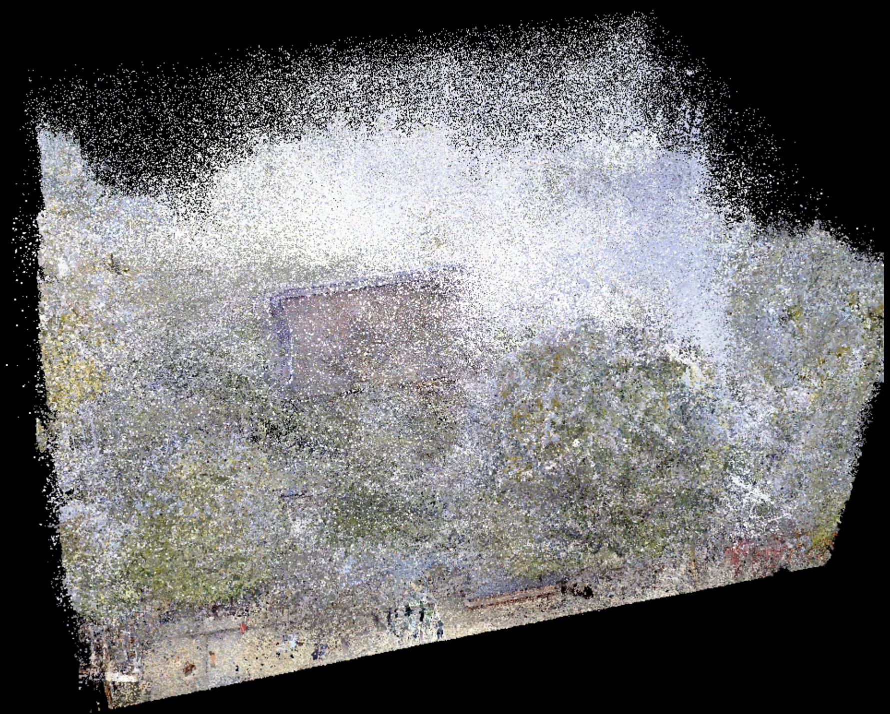
Isn't it possible to also make noise transparent?



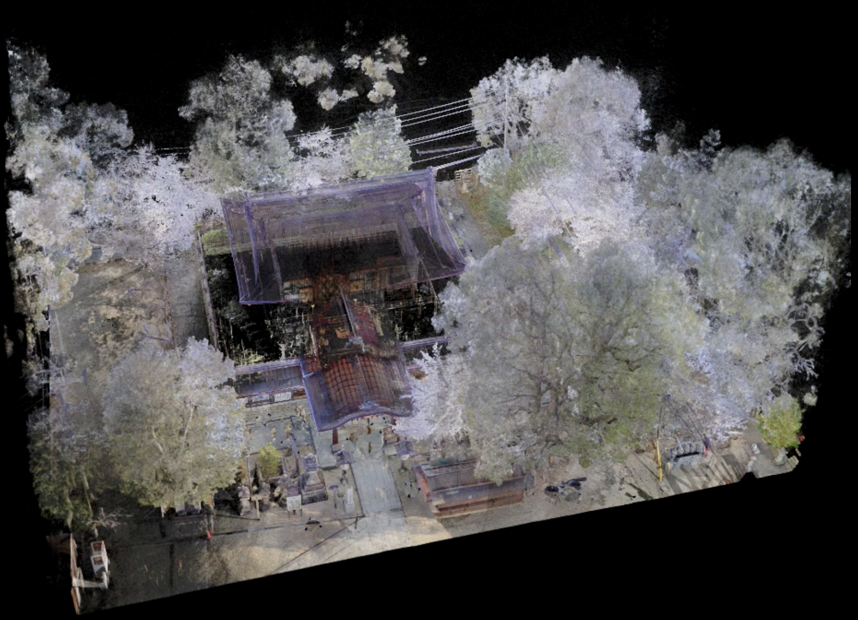
Fune-hoko float

Our new method: “Stochastic Noise Transparentization”

Laser-scanned point cloud



After applying SPBR



Research purpose

- **Stochastic Noise Transparentization**
  - **Demonstrate the effect** through validation experiments
  - **Demonstrate the applicability** by applying to actual laser-scanned noisy point clouds

Establish a "noise-robust" transparent visualization method
that helps researchers and engineers to analyze, understand and use

Stochastic Point-Based Rendering（SPBR[1]）

Step 1 :
Randomly divide into ***L*** point clouds

Step 3 :
Average the L intermediate images (**Stochastic Noise Transparentization**)

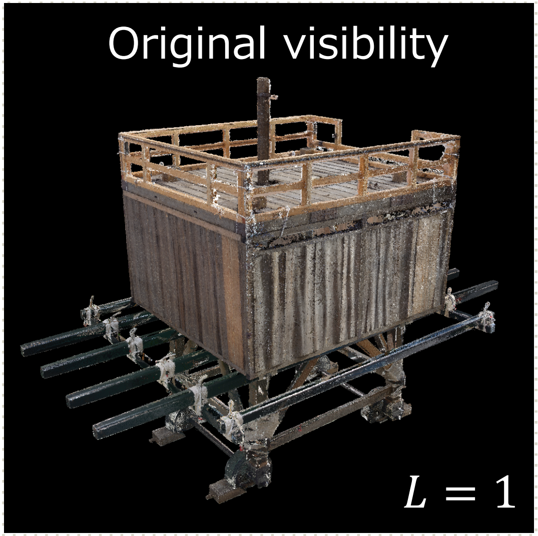
Raw point cloud
(Input)

Step 2 :
Point projection **for each ensemble**

[1] S. Tanaka, K. Hasegawa, N. Okamoto, et al, "*See-through Imaging of Laser-Scanned 3D Cultural Heritage Objects based on Stochastic Rendering of Large-Scale Point Clouds*", XXIII ISPRS Congress 2016

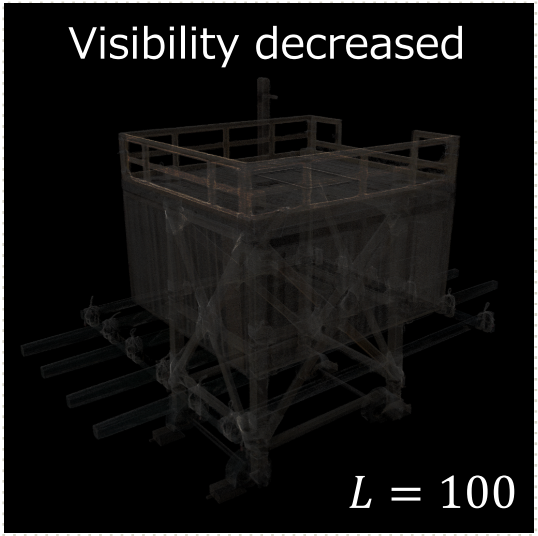
Now we are developing

- **Automatic Brightness Adjustment Method**
  - If L increases too much, **visibility may decrease**
  - **Improve the visibility while maintaining opacity** by amplifying the brightness of the input image



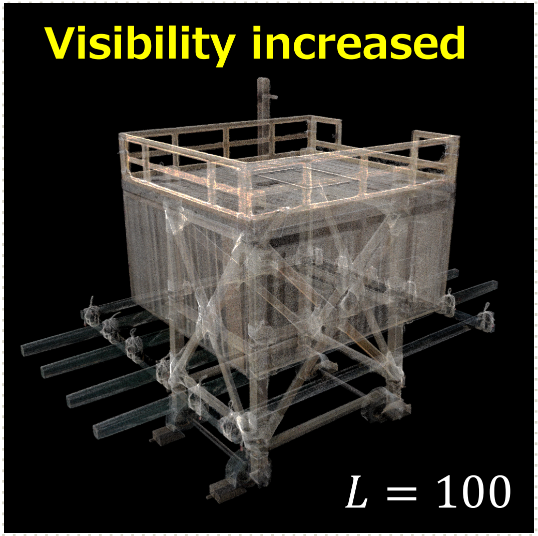
Original image

SPBR



Input image

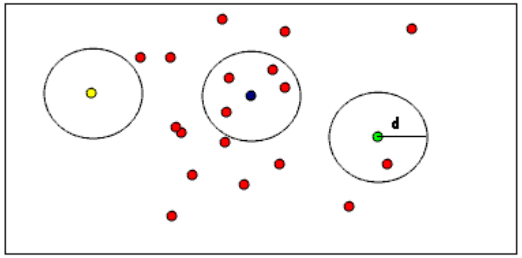
Our method



Output image

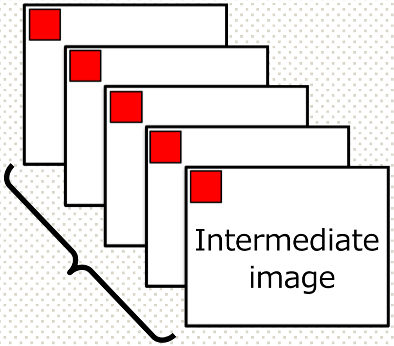
Stochastic Noise Transparentization: Comparison with conventional methods

- **Conventional noise reduction methods**
  - Manually remove noise one by one
    → It **takes time and effort**
  - Search neighbor points for each 3D point
    → It is **not suitable for large-scale point clouds** because it takes a long time to calculate



http://pointclouds.org/documentation/tutorials/remove_outliers.php

- **Our method**
  - Smooth the corresponding pixels in the L intermediate images
    → **Image resolution does not decrease** and **high-speed processing is possible**
  - The greater the number of intermediate images, the better the quality of the average image
    → **Make better use the redundancy of large-scale data**



3． Validation Experiments

Validation experiments (1): Overview — For artificial point clouds —

Experimental purpose

1. **Quantitative evaluation** of noise transparentization
2. **Estimation of L** required for noise transparentization

Experimental method

Step1. Prepare **"non-noisy"** and **"noisy"** point clouds

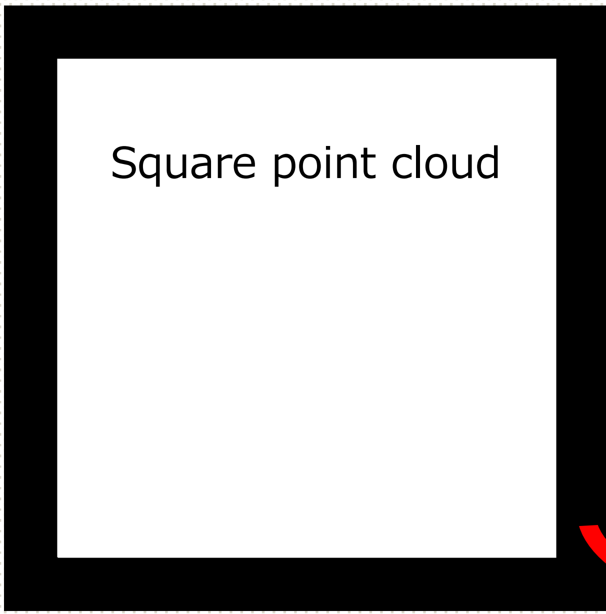
Step2. Apply our method to both point clouds

Step3. Evaluate quantitatively for the obtained two images

- Index1: Difference in average pixel value
- Index2: MSE (Mean Square Error)

Validation experiments (1): Two kinds of point clouds used in the experiment

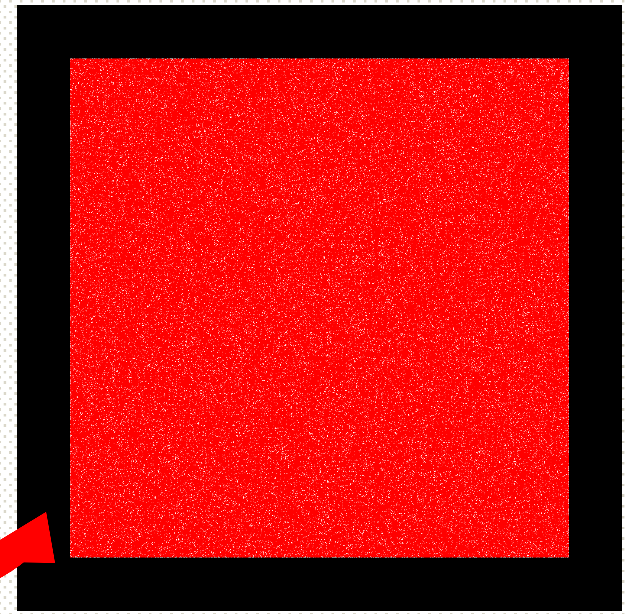
Non-noisy image（$L = 1$）



Bounding Box Size:
$1\times1\times0$

Image Resolution:
1024^2(pixel)

Noisy image（$L = 1$）



Shift positions according to a 3D Gaussian distribution

Noise point color	Red
Probability to shift	$10(\%)$
Standard Deviation	$\sigma_{\mathrm{raw}} = \sqrt{10}(\mathrm{pixel})$

Validation experiments (1): Conditions of L required for noise transparentization

- **The use of central limit theorem**
  - As L increases, **the initial variance of noise decreases in inverse proportion to L**
  - Let σ^2 be the variance decreased by the central limit theorem:

$$\boxed{\sigma^2 \approx \frac{\sigma_{\text{raw}}^2}{L}}$$

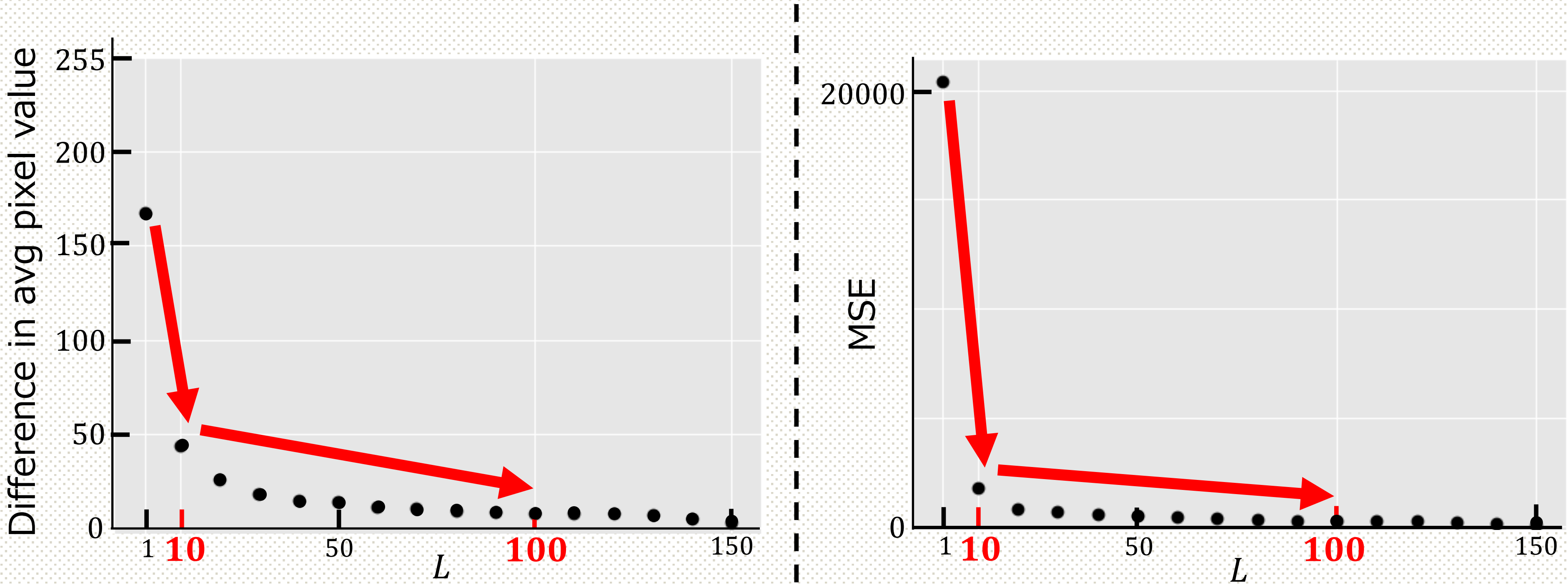
Minimum condition

$$\sigma < 1 \text{ (pixel)}$$
$$\sigma^2 < 1$$
$$\frac{\sigma_{\text{raw}}^2}{L} < 1$$
$$L > \sigma_{\text{raw}}^2 = \mathbf{10}$$

Sufficient condition

$$\sigma < 0.3 \text{ (pixel)}$$
$$\sigma^2 < 0.09$$
$$\frac{\sigma_{\text{raw}}^2}{L} < \frac{9}{100}$$
$$L > \sigma_{\text{raw}}^2 \times \frac{100}{9} \approx \mathbf{100}$$

Validation experiments (1): Experimental results



Until around $\boldsymbol{L = 10}$, the noise influence decreases drastically.
After that, it gradually decreases until around $\boldsymbol{L = 100}$

Validation experiments (2): Overview — For laser-scanned point clouds —

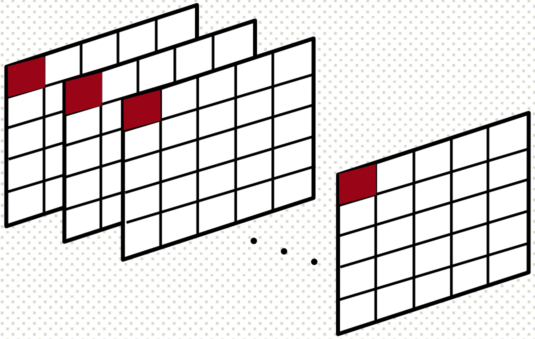
Experimental purpose

- Analysis of **how the standard deviation** of the corresponding pixel value of L intermediate images **changes by ensemble averaging**

Experimental method

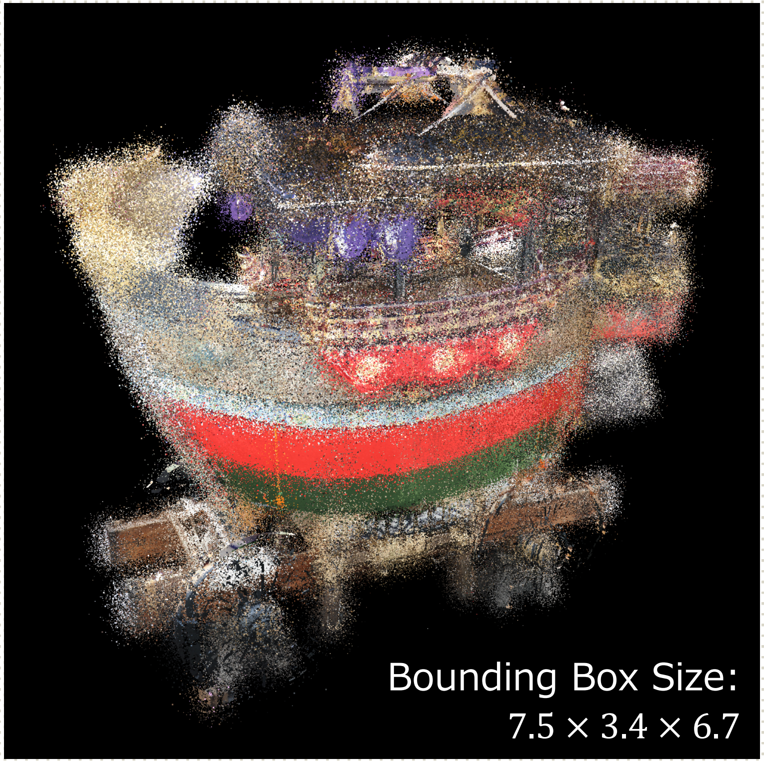
Step1. Prepare **"coordinate"** and **"color"** noisy point clouds

Step2. In L intermediate images, calculate the standard deviation of pixel value for corresponding pixels



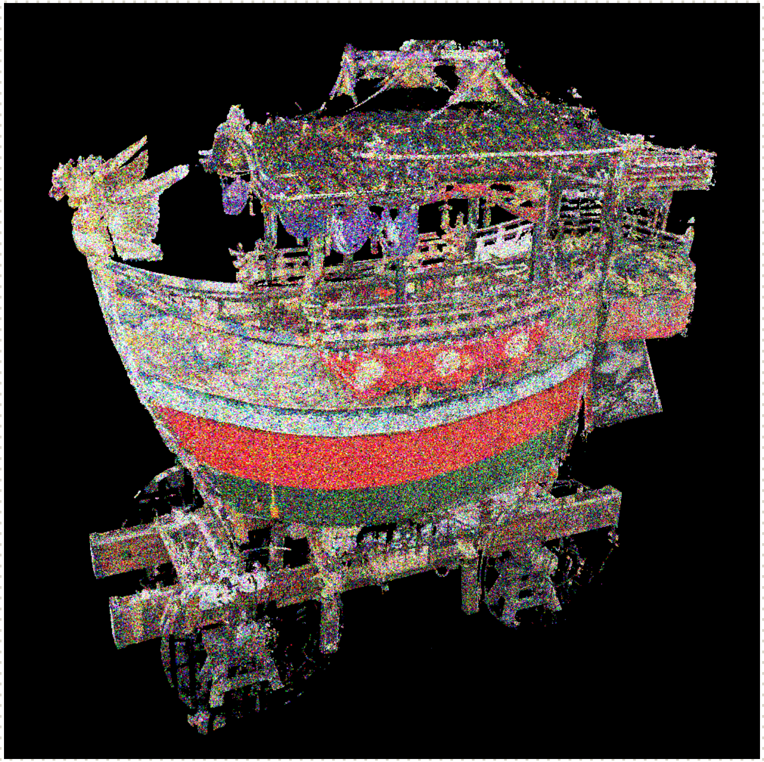
Validation experiments (2): Two kinds of point clouds used in the experiment

Coord noise point cloud



Probability to shift	10(%)
Variance	0.1 (pixel^2)

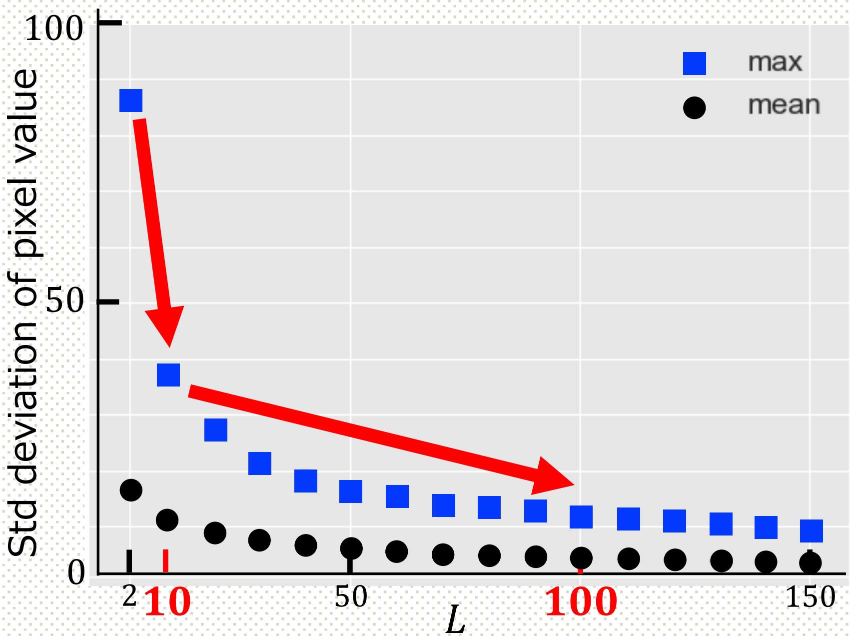
Color noise point cloud



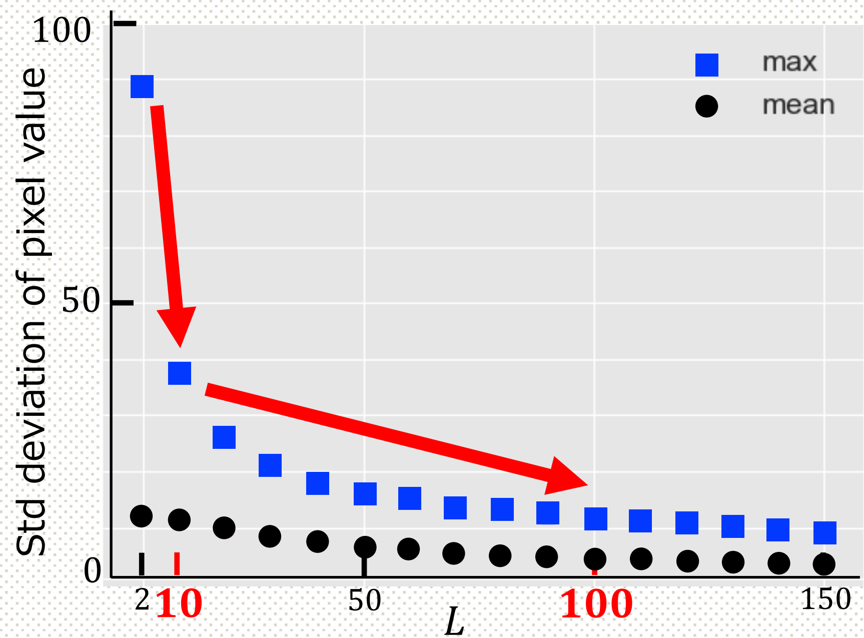
Probability to shift	10(%)
Variance	100

Validation experiments (2): Experimental results

Coord noise point cloud



Color noise point cloud

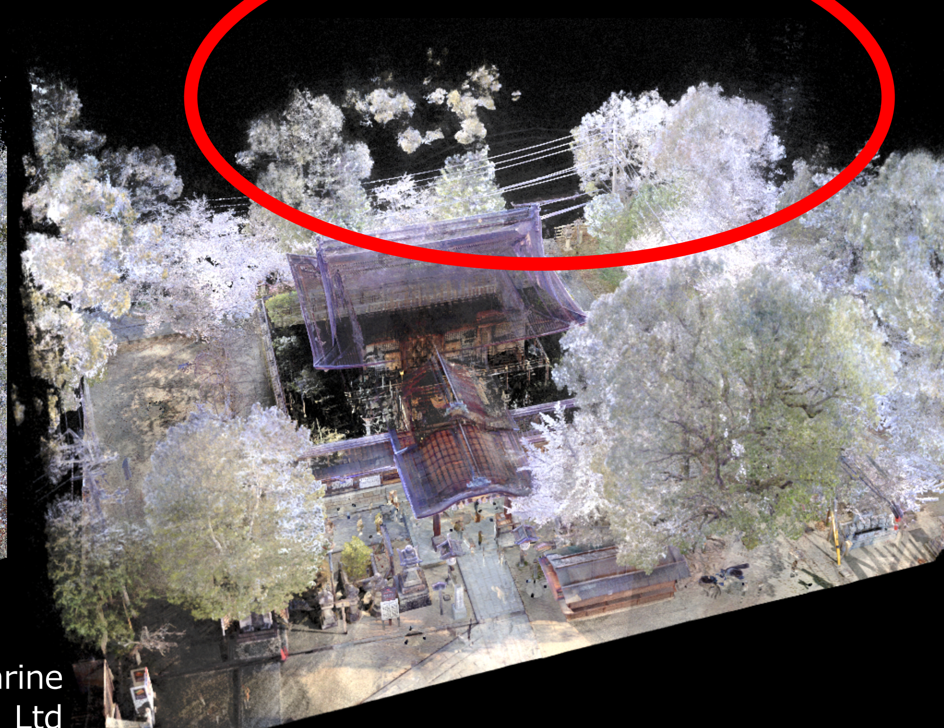


Whether the noise is in the coord space or the color space,
the influence of the noise decreases as L increases

Visualization results（1/3）: Trees with leaves

Before (raw point cloud)

After ($L = 100$)



Fujinomori Shinto Shrine
Laser-scanning: Shrewd Design Co. Ltd

Visualization results（2/3）: Reflective objects

Before (raw point cloud)

After ($L = 100$)

Visualization results（3/3）: Powder dust in factory

Before (raw point cloud)

After ($L = 100$)

Laser-scanning: Shrewd Design Co. Ltd

5． Summary

Summary

1. **Evaluated the effect** of noise transparentization quantitatively
2. **Estimated the value of L** required for noise transparentization
3. **Demonstrated the applicability** of noise transparentization by applying to laser-scanned noisy point clouds

↓

We have established a **"noise-robust"** transparent visualization method

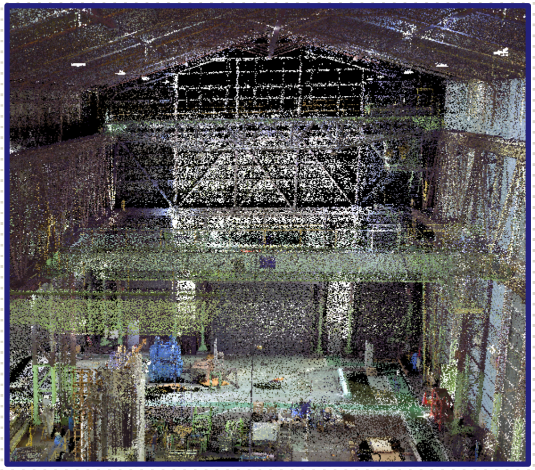
Q & A session

Causes of noise occurring

- In laser-scanning, trees with leaves trembling in the wind make the acquired positional information inaccurate

Trees with leaves

Glass windows



Powder dust

質問

- 宮地: 3次元的なノイズ除去と比較しての利点は？

- なぜ Gaussian noise なのか？
- 実際の計測ノイズは本当に Gaussian noise か？

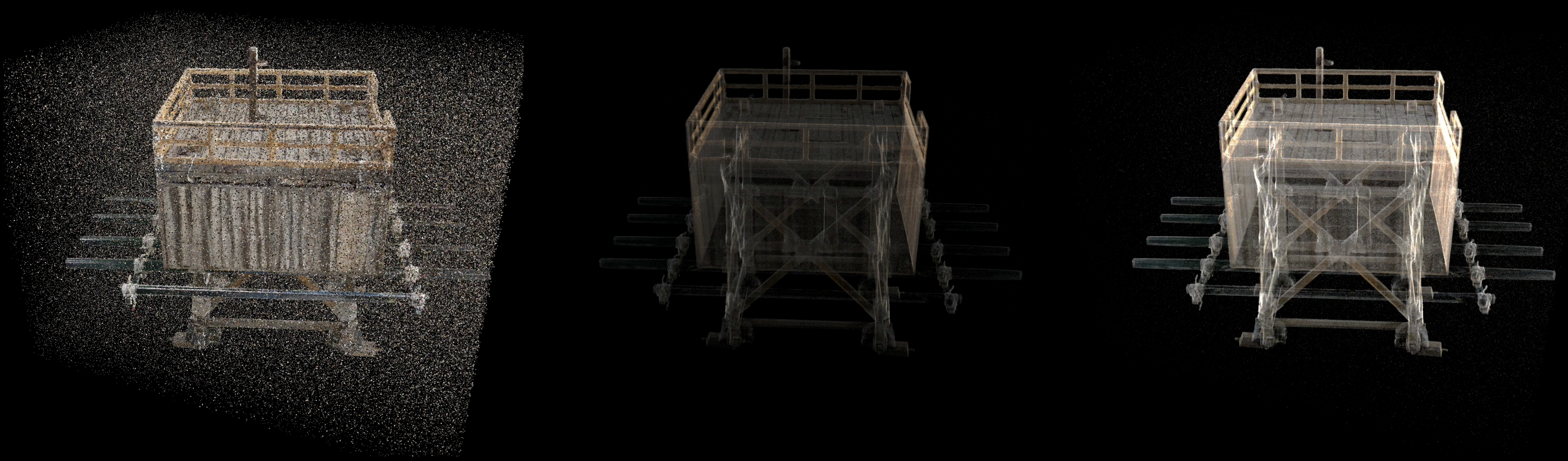
- 坂本: 消えてほしくないものまで透明化されているのでは？

- 伊藤: 輝度調整でうまくいかないことはない？

研究成果のまとめ

ノイズ透明化
（視認性低下）

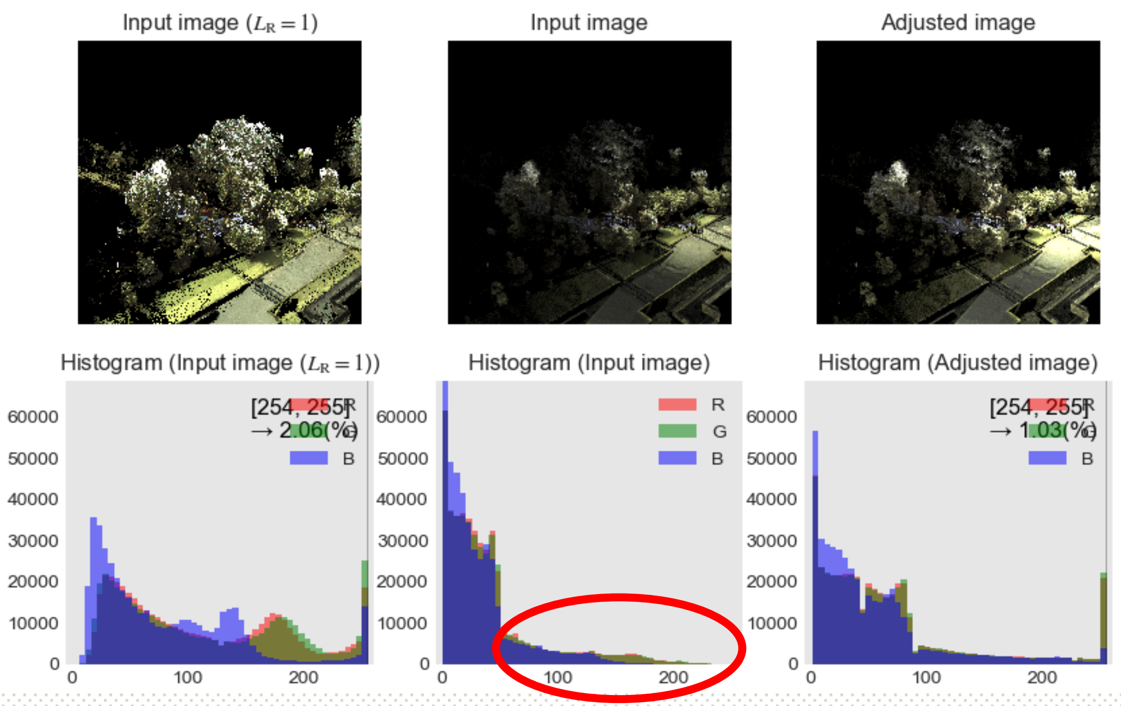
輝度調整
（視認性向上）



今後の展望

今後の展望

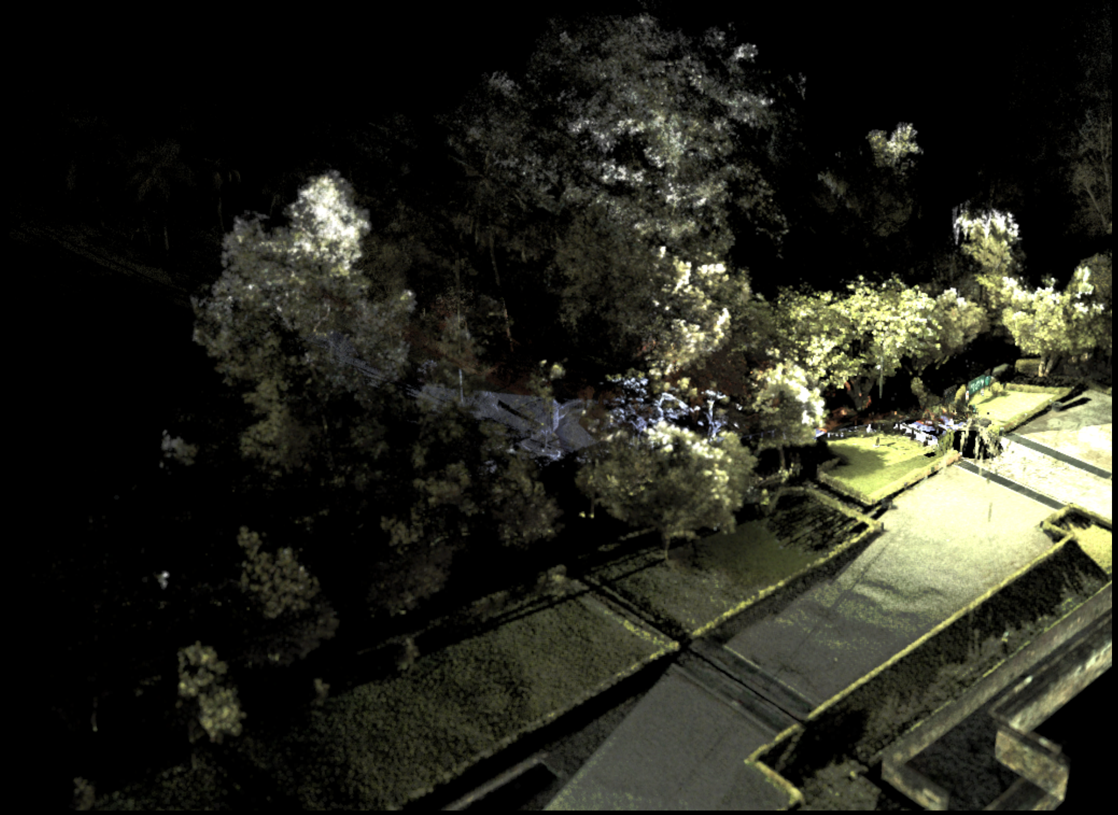
- **輝度調整手法の改善**
  - 入力画像の**輝度値分布にロバスト**な手法の確立



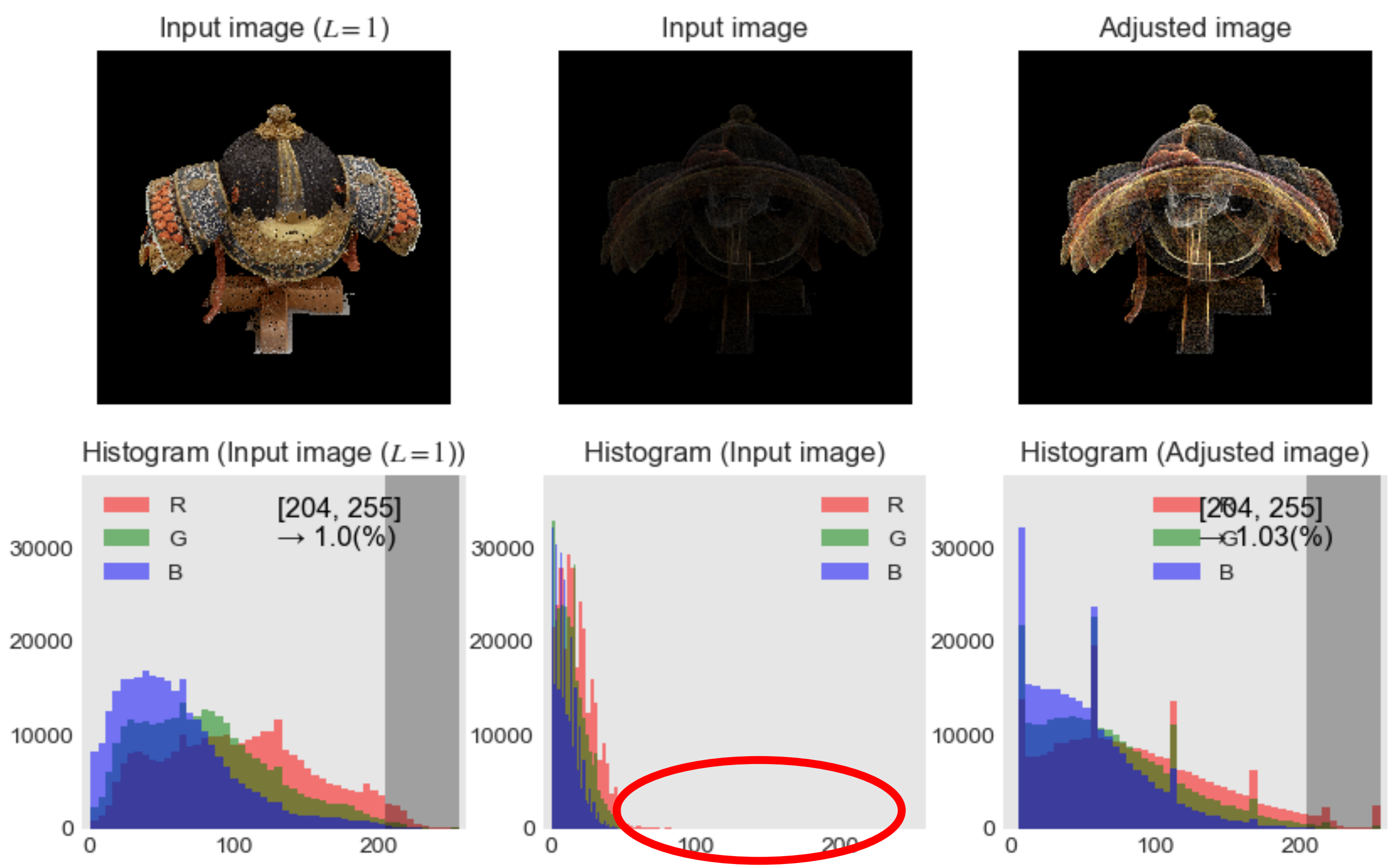
もともと輝度値が高いピクセルが多く存在している

輝度調整結果

輝度調整後（$p = 1.7$）



輝度値分布が良い画像の例



もともと輝度値が高いピクセルが
存在していない

検証実験１（1/4）

検証方法

1. 人工点群を用意し，人工的にノイズを付与
2. SPBRで両者の画像（元画像と評価画像）を生成
3. L を上げていき，**２枚の画像の画質を比較**

画質の評価指標

1. 平均輝度値
2. MSE（平均二乗誤差）

$$\mathrm{MSE} = \frac{1}{l \times m} \sum_{i=1}^{l} \sum_{j=1}^{m} \{I(i,j) - K(i,j)\}^2$$

画像サイズ　：$l \times m$
元画像　：I
評価画像　：K

ノイズ透明化に必要なリピートレベルの値

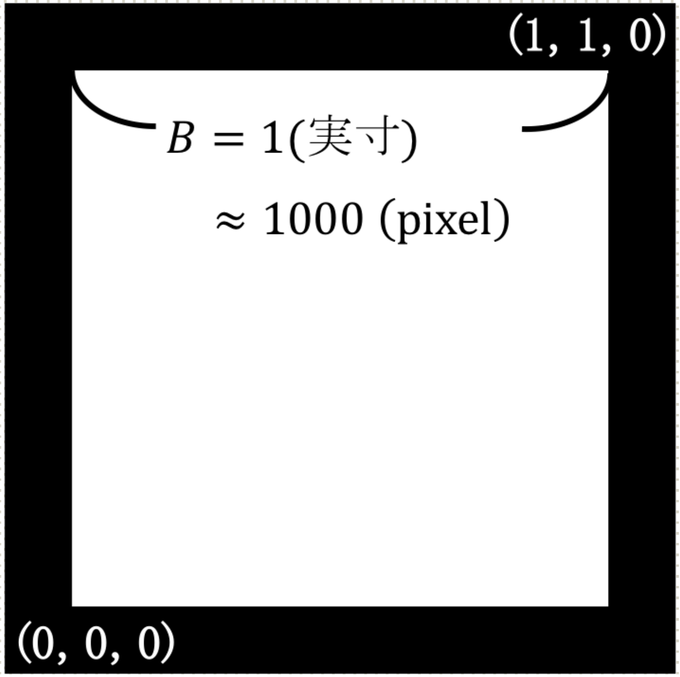
状況設定

- 人工点群の一辺の長さ：B

$$B = 1(\text{実寸}) \times \frac{10^3(\text{pixel})}{1(\text{実寸})}$$
$$= 10^3\ (\text{pixel})$$

- ノイズの初期分散： σ_{init}^2

$$\sigma_{\text{init}}^2 = 1.0\times10^{-5}(\text{実寸}^2)\times\frac{10^6(\text{pixel}^2)}{1^2(\text{実寸}^2)}$$
$$= 10\ (\text{pixel}^2)$$



想定する人工点群

ノイズ透明化プロセス

確率的ノイズ透明化

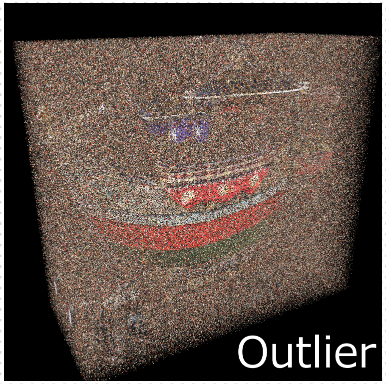
可視化対象よりも
ノイズが先に透明になる

検証実験 3

検証実験３： 模擬ノイズによる実験

◻ 検証目的

- **計測ノイズを模した２種類のノイズ**に対する，ノイズ透明化効果の実証



◻ 検証方法

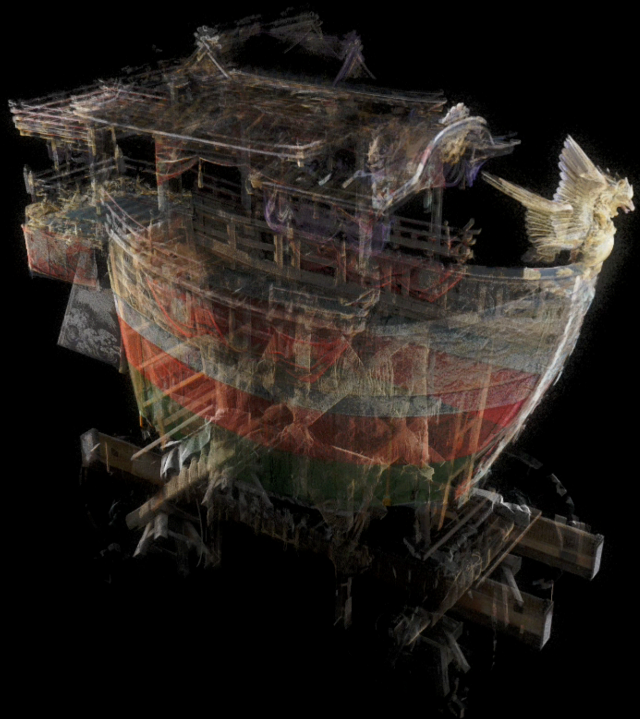
1. 計測点群に対して，Gaussian noise と Outlier noise の２種類のノイズを人工的に付与
2. L を上げていき，ノイズ透明化効果を検証

検証実験３：実験結果

Gaussian noise

$10\%, \sigma^2 = 0.1$

$L = 1$



$\boldsymbol{L = 100}$

検証実験３：実験結果

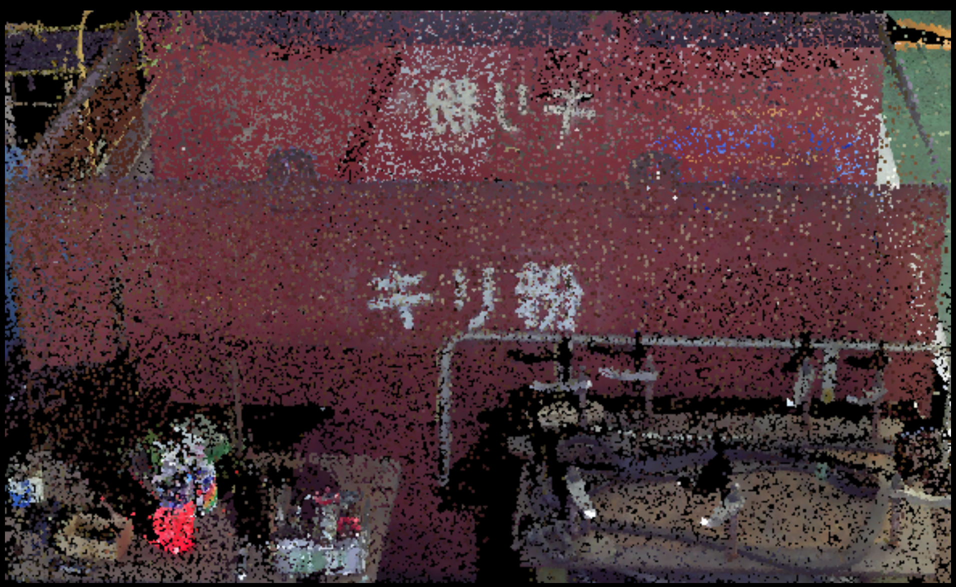
Outlier noise
1%

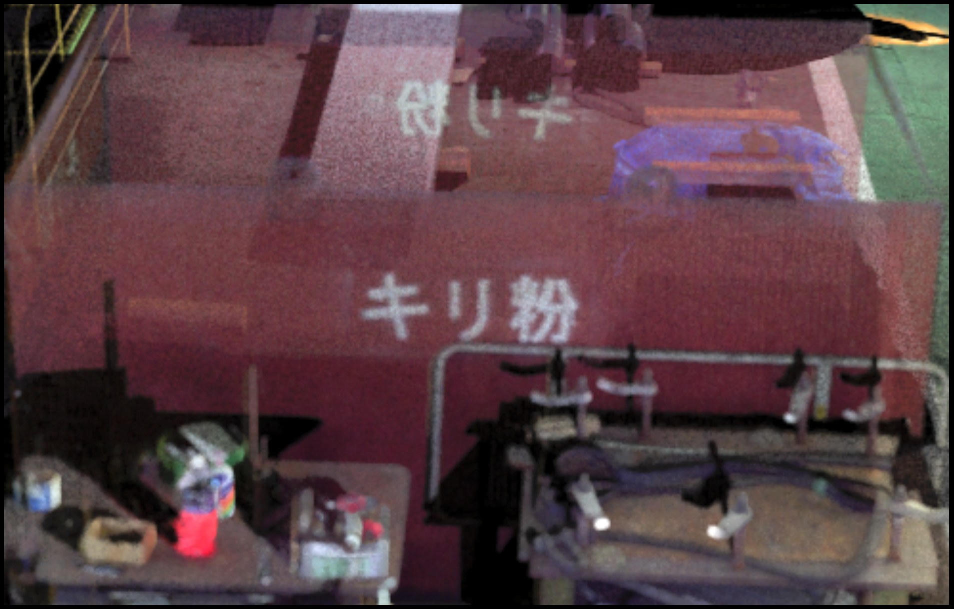
$L = 1$

$\boldsymbol{L = 20}$

確率的ノイズ透明化

確率的ノイズ透明化





輝度調整

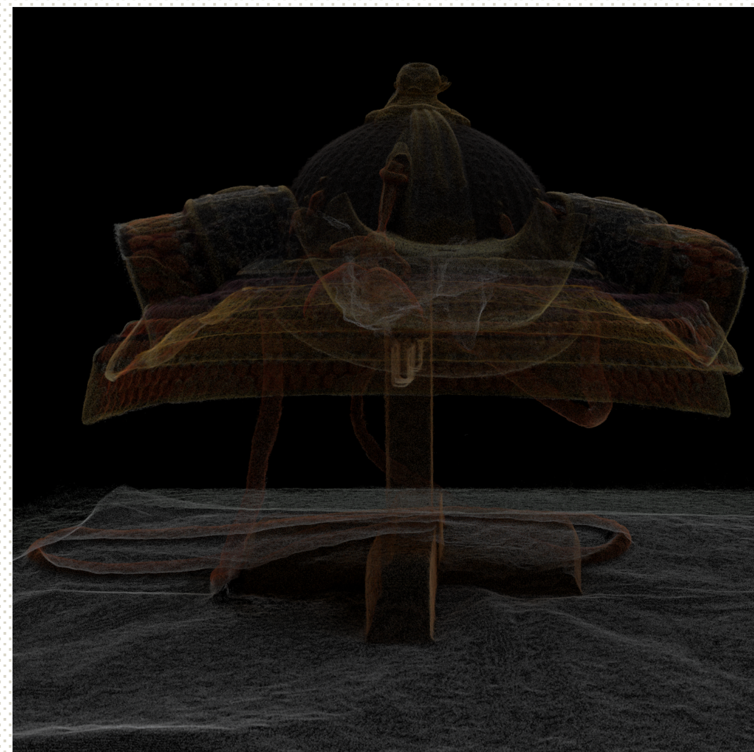
確率的ノイズ透明化の問題点

□ 視認性の低下

- 点数が少ない場合に，リピートレベルを上げすぎると、**不透明度の低下**により，**視認性が低下**することがある

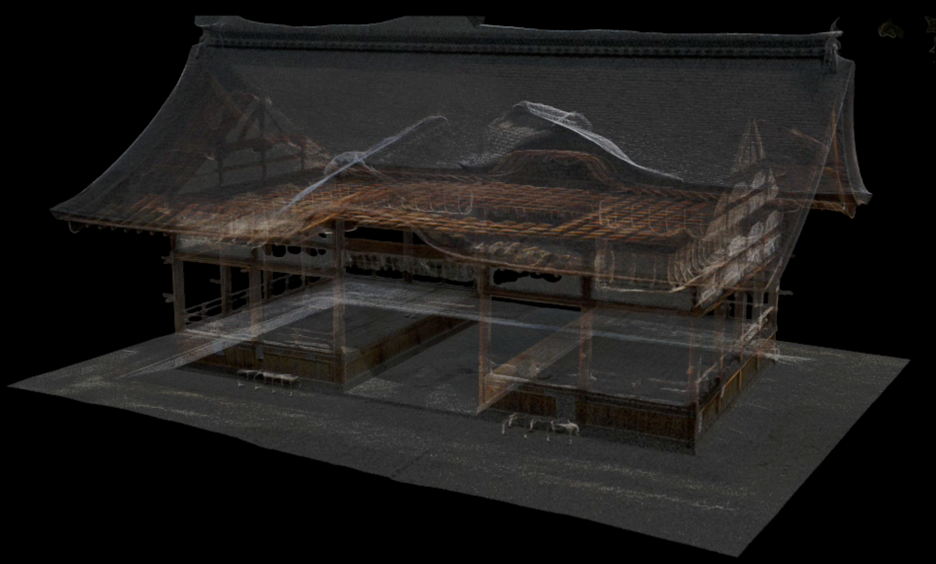
点数：6,706,417 点，計測：(株)シュルード設計

ノイズ透明化

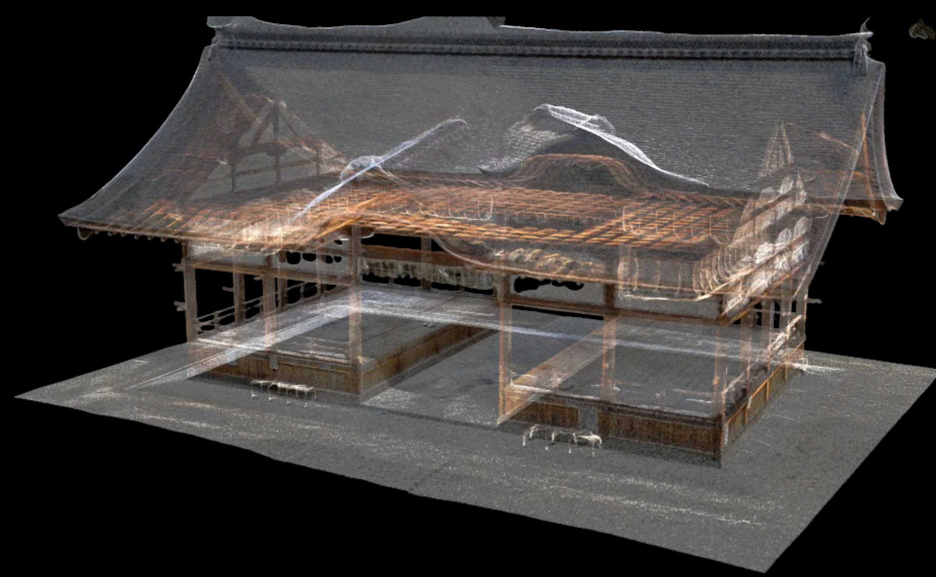


輝度調整（4/4）

輝度調整前



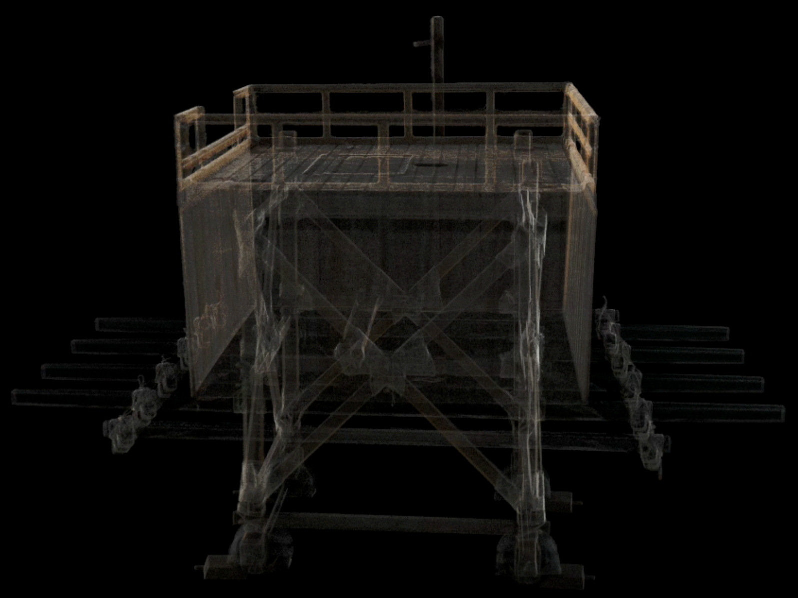
輝度調整後（$p = 2.52$）



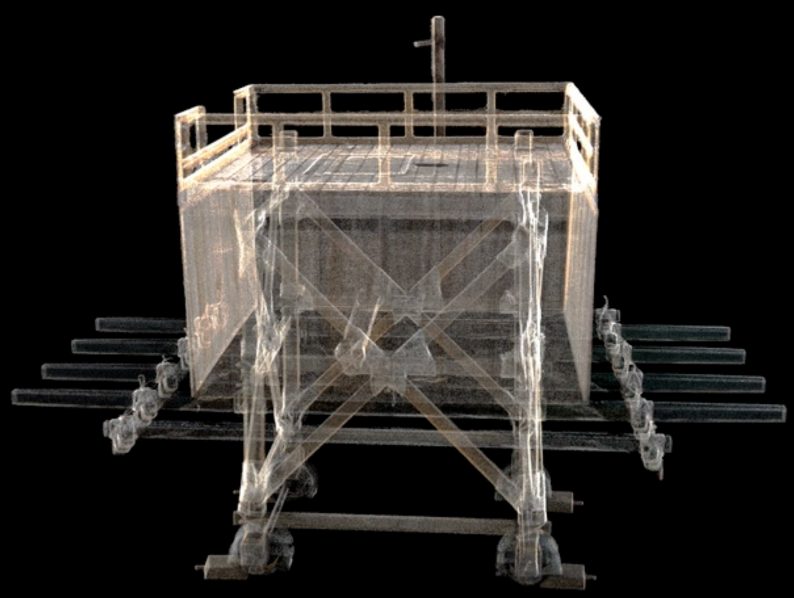
藤森神社–拝殿–，計測：(株)シュルード設計

輝度調整

輝度調整前



輝度調整後（$p = 3.57$）



輝度調整

不透明度を維持したまま視認性の向上を実現

輝度調整前

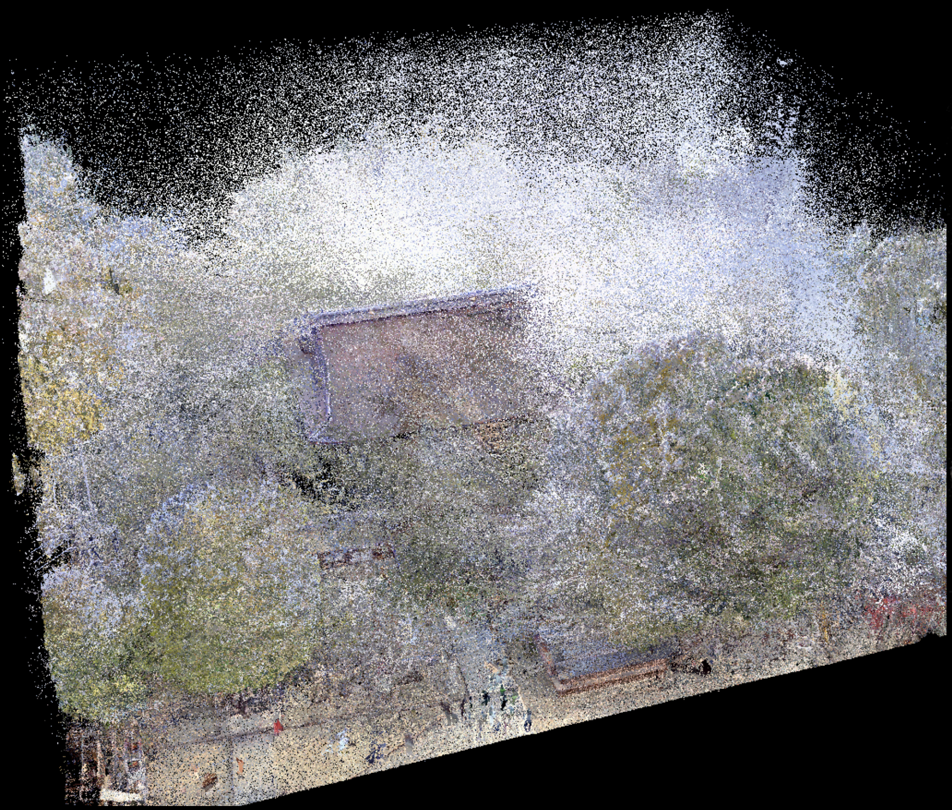
輝度調整後（$p = 2.99$）

計測点群の点数

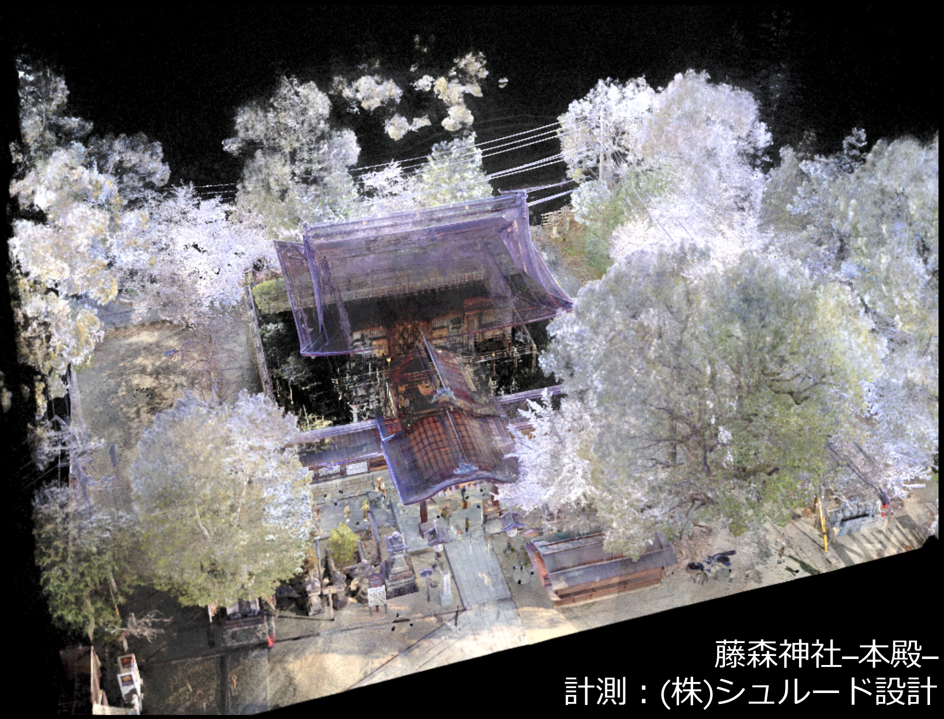
船鉾：25,427,464 点

藤森神社―本殿―：1,165,757,917 点

ノイズ透明化前（計測点群）



ノイズ透明化後（$L = 100$）

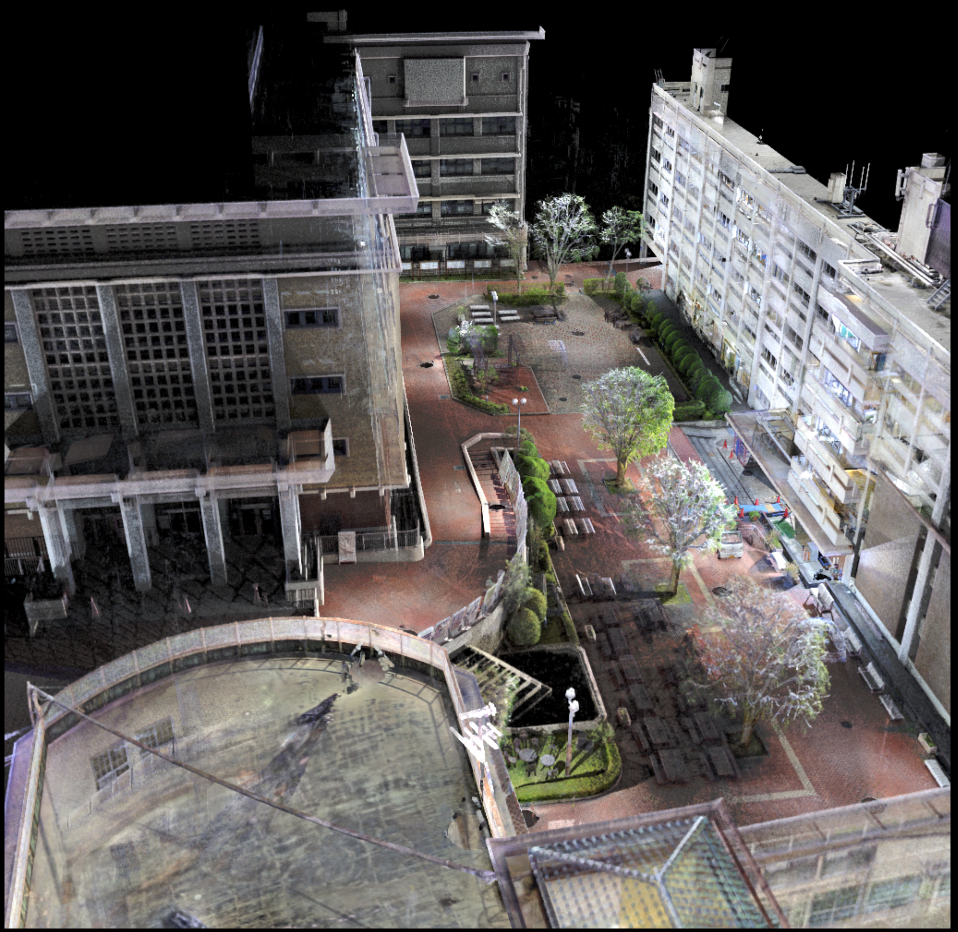


藤森神社–本殿–
計測：(株)シュルード設計

京都女子大学：1,942,127,651 点

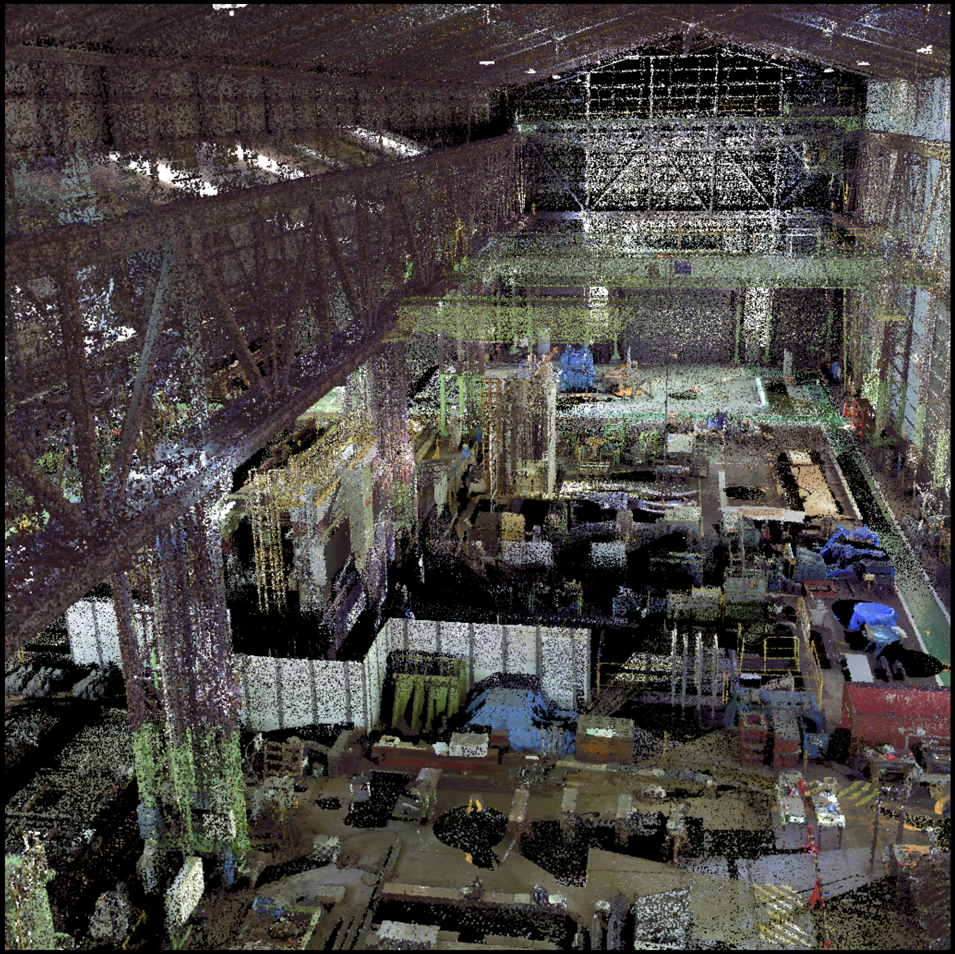
ノイズ透明化前（計測点群）

ノイズ透明化後（$L = 100$）



工場：691,706,402 点

ノイズ透明化前（計測点群）



ノイズ透明化後（$L = 100$）

八幡山： 7,856,886 点

大兜： 3,343,872 点

Stochastic Noise Transparentization: Comparison with conventional method

- **Conventional method**
  - Manually remove noise one by one
    → **It takes time and effort**
  - Perform statistical analysis for each point
    → **It is not suitable for large-scale point clouds because it takes a long time to calculate**

- **Our method**
  - The greater the number of intermediate images, the better the quality of the averaging image
    → **Make better use the redundancy of large-scale data**
  - Smooth the corresponding pixels in the L intermediate images
    → **Image resolution does not decrease and high-speed processing is possible**