Accurate Point Cloud Generation for 3D Machine Vision Applications using DLP® Technology and Industrial Camera

About Test Results

The DLP Structured Light Software Development Kit (SDK) offers a complete software solution for 3D scanning and point cloud generation. The point cloud data below was generated using the DLP Structured Light SDK with a DLP® LightCrafter™ 4500 and Point Grey Flea3 USB camera. The generated point cloud data was visualized using MeshLab.

Related Documentation From Texas Instruments

- DLPC350 Data Sheet: DLP Digital Controller for Portable Advanced Light Control, TI literature number DLPS029
- DLP4500 Data Sheet: DLP 0.45 WXGA Visible DMD, TI literature number DLPS028
- DLP4500NIR Data Sheet: DLP 0.45 WXGA Near-Infrared DMD, TI literature number DLPS032
- User's Guide: DLPC350 Programmer's Guide, TI literature number DLPU010
- Application Note: Using DLP® Development Kits for 3D Optical Metrology Systems, TI literature number DLPA026
- Application Note: Using DLP® LightCrafter™ 4500 Triggers to Synchronize Cameras to Patterns, TI literature number DLPA036

If You Need Assistance

Refer to the DLP and MEMS TI E2E Community support forums

Calibration Results

This chapter provides test data from the DLP Structured Light SDK for camera and projector calibration module. When the camera and projector calibration parameters are found, the output is used to generate the system optical rays which ultimately allow line intersections to be calculated for point cloud generation.

To calibrate the system, the following procedure is used:

1. From main menu of software, select “1: Generate camera calibration board and enter feature measurements” and follow instructions
   a. Note: Measure the height and width of the printed calibration board in the desired units of the point cloud

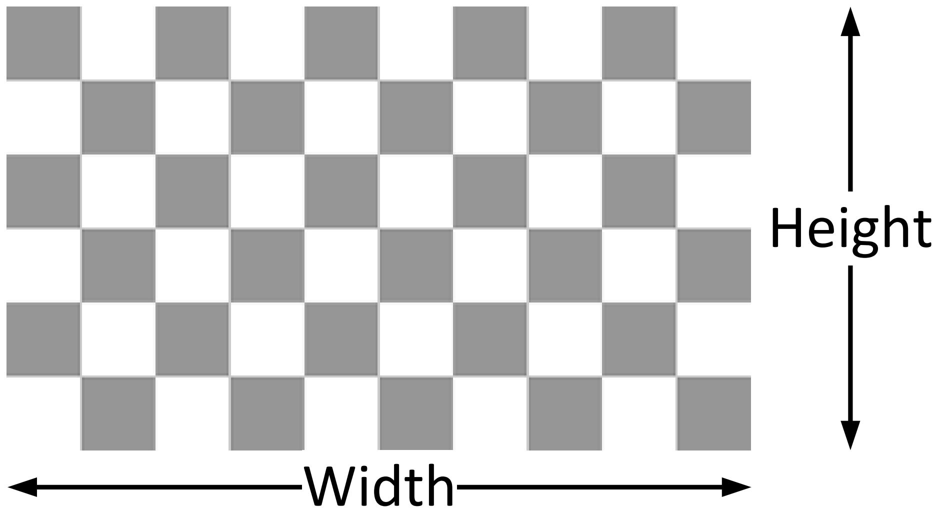

Figure 1 Camera calibration board measurement

2. From main menu of software, select “2: Calibrate camera (all camera data and project white pattern)” and follow instructions
3. From main menu of software, select “3: Calibrate system (update camera extrinsics and all projector data)”

The following images show the camera captures of the printed calibration board and projected calibration board after removing the printed calibration board from the projected.

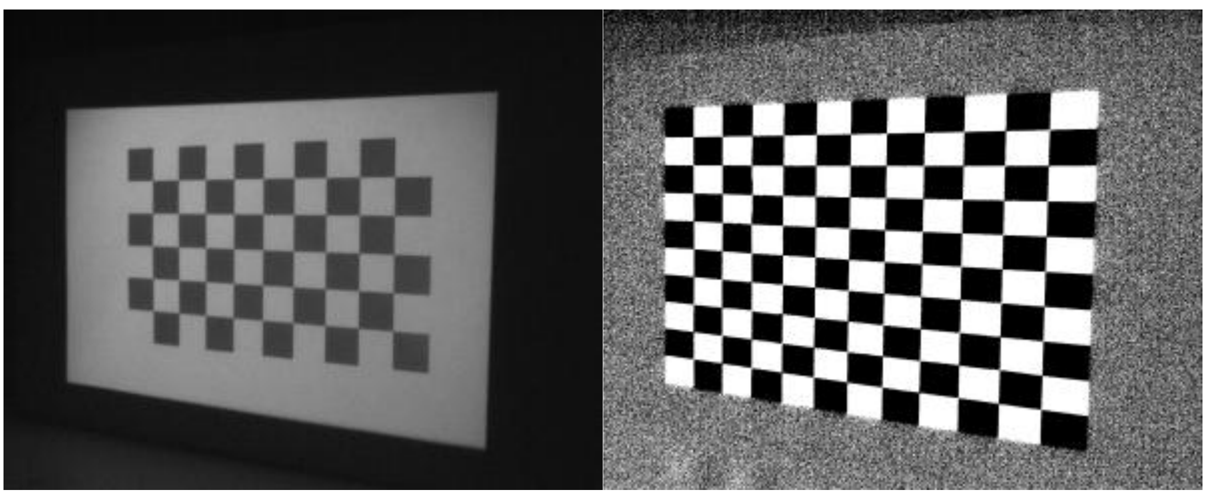

Figure 2 Printed calibration board and projected calibration board position 1

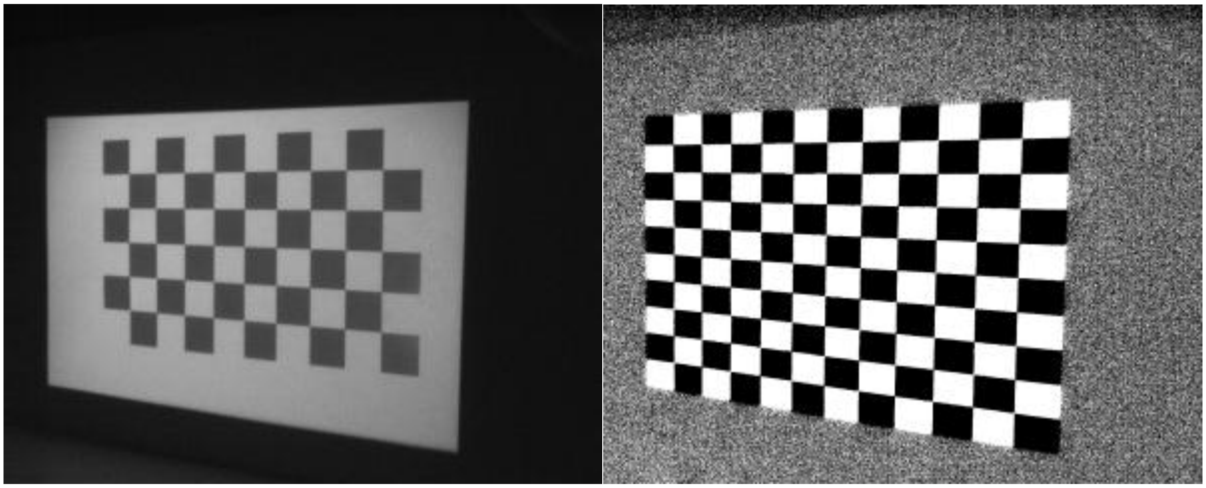

Figure 3 Printed calibration board and projected calibration board position 2

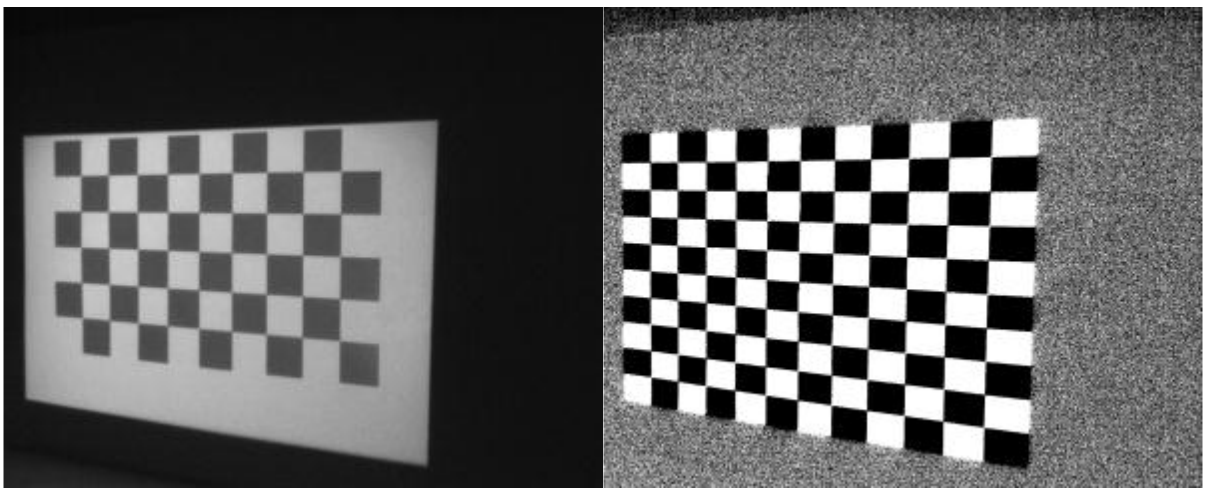

Figure 4 Printed calibration board and projected calibration board position 3

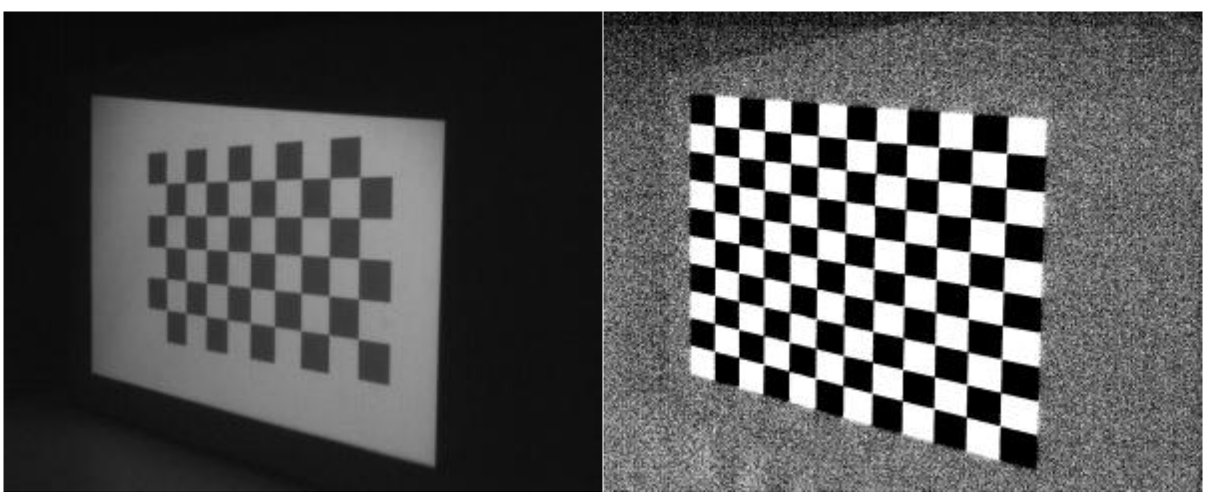

Figure 5 Printed calibration board and projected calibration board position 4

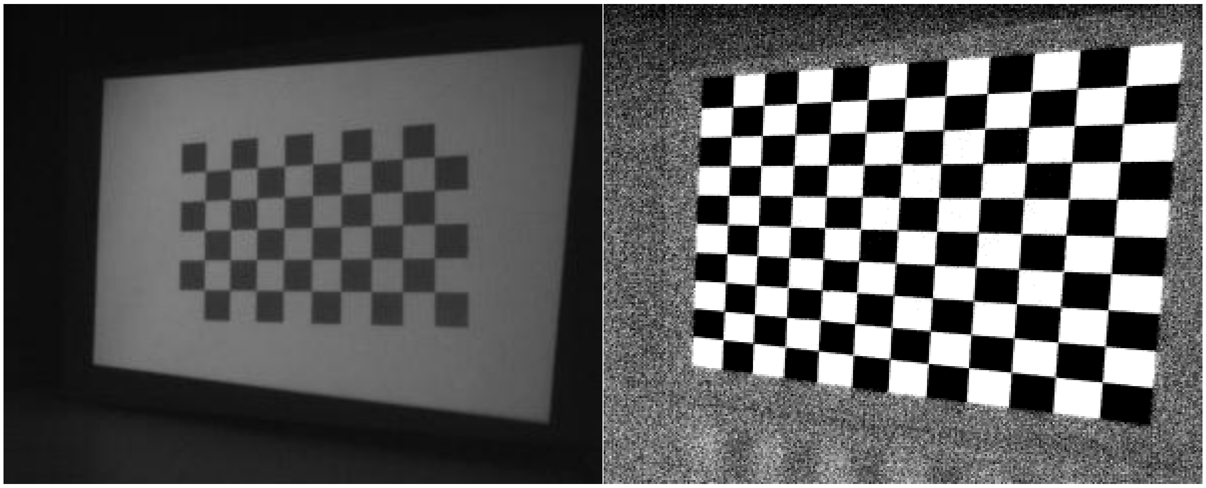

Figure 6 Printed calibration board and projected calibration board position 5

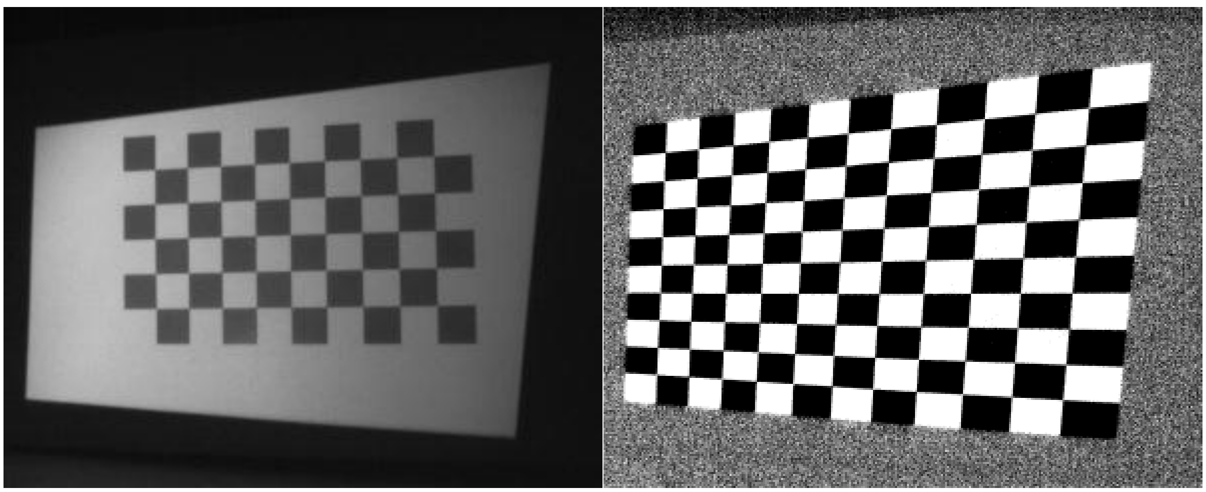

Figure 7 Printed calibration board and projected calibration board position 6

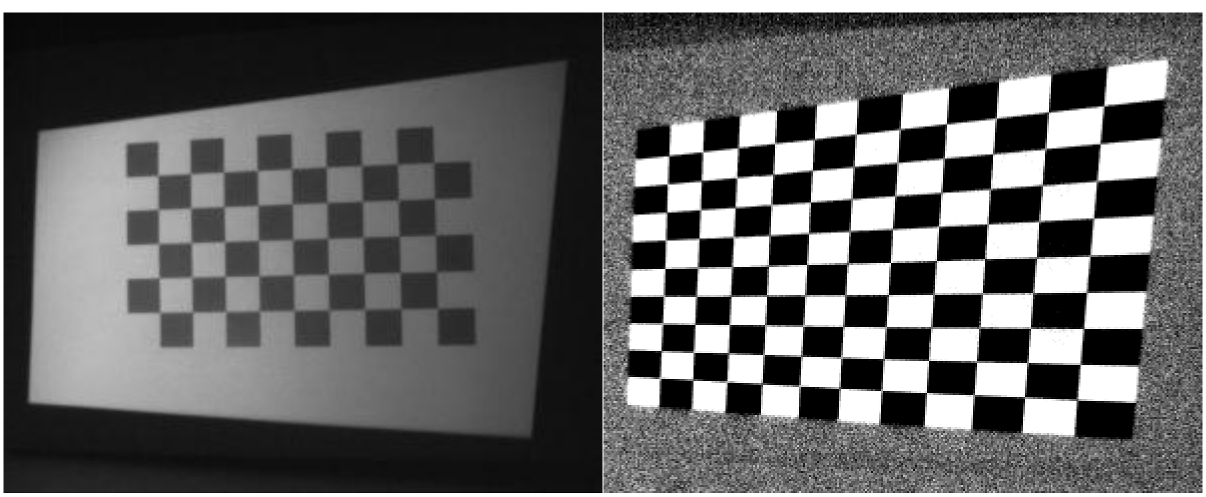

Figure 8 Printed calibration board and projected calibration board position 7

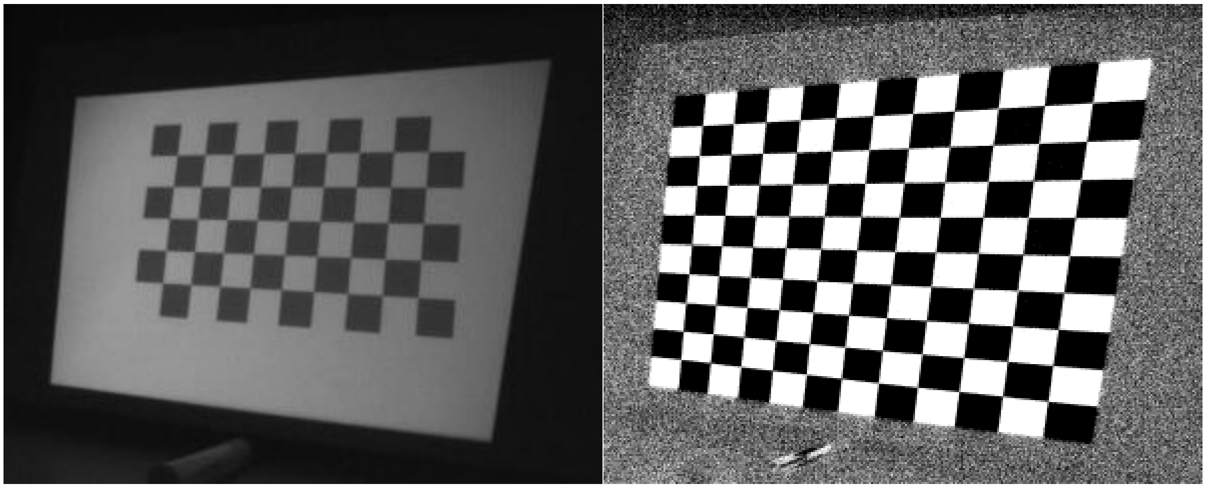

Figure 9 Printed calibration board and projected calibration board position 8

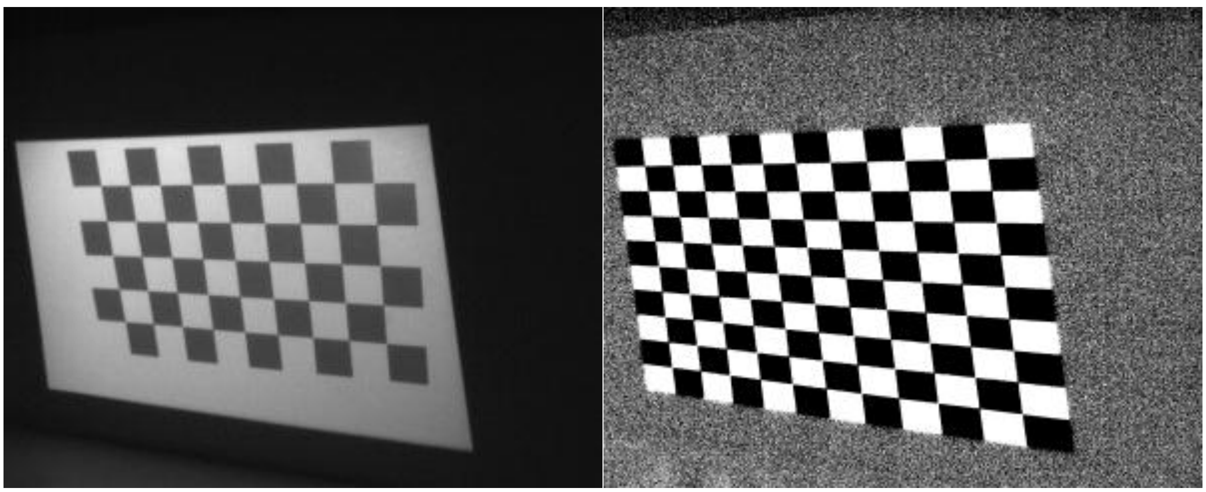

Figure 10 Printed calibration board and projected calibration board position 9

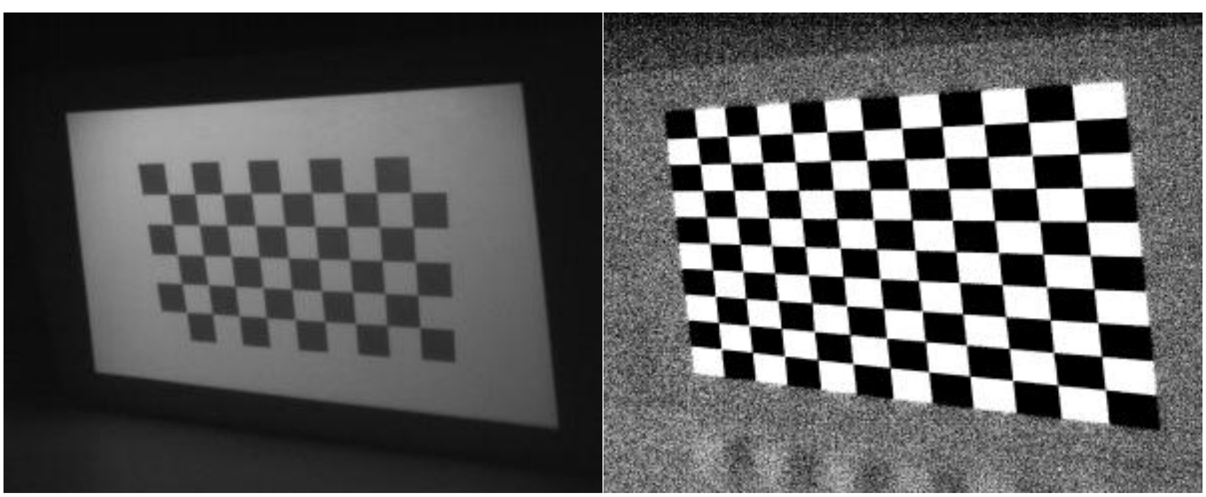

Figure 11 Printed calibration board and projected calibration board position 10

The following images should the calibration XML files generated for the camera and projector.

camera_calibration_data.xml | projector_calibration_data.xml


```xml
<?xml version="1.0"?>
<opencv_storage>
<DLP_CALIBRATION_DATA>1</DLP_CALIBRATION_DATA>
<calibration_complete>1</calibration_complete>
<calibration_of_camera>1</calibration_of_camera>
<image_columns>1280</image_columns>
<image_rows>1024</image_rows>
<model_columns>1280</model_columns>
<model_rows>1024</model_rows>
<reprojection_error>1.3752874853193664e-001</reprojection_error>
<intrinsic type_id="opencv-matrix">
  <rows>3</rows>
  <cols>3</cols>
  <dt>d</dt>
  <data>
    1.7465041853200389e+003 0. 6.3772881326798790e+002 0.
    1.7500843319722210e+003 5.1632415213743172e+002 0. 0. 1.</data></intrinsic>
<distortion type_id="opencv-matrix">
  <rows>5</rows>
  <cols>1</cols>
  <dt>d</dt>
  <data>
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    3.8975171677462623e-004 -2.0813966898194735e-004
    -1.3310541110653227e+000</data></distortion>
<extrinsic type_id="opencv-matrix">
  <rows>2</rows>
  <cols>3</cols>
  <dt>d</dt>
  <data>
    1.0077933576639649e-001 4.6424730615050602e-001
    -4.3067282944569359e-002 -8.6817432413861582e+001
    -5.6214553174401601e+001 5.5937845804204107e+002</data></extrinsic>
</opencv_storage>
```


Figure 12 Camera calibration XML output file camera_calibration_data.xml | projector_calibration_data.xml


```xml
<?xml version="1.0"?>
<opencv_storage>
<DLP_CALIBRATION_DATA>1</DLP_CALIBRATION_DATA>
<calibration_complete>1</calibration_complete>
<calibration_of_camera>0</calibration_of_camera>
<image_columns>1280</image_columns>
<image_rows>1024</image_rows>
<model_columns>912</model_columns>
<model_rows>1140</model_rows>
<reprojection_error>3.9379608297983898e-001</reprojection_error>
<intrinsic type_id="opencv-matrix">
  <rows>3</rows>
  <cols>3</cols>
  <dt>d</dt>
  <data>
    1.2992683297032597e+003 0. 4.4089914044914326e+002 0.
    1.3004633529916375e+003 7.9905029183791737e+002 0. 0. 1.</data></intrinsic>
<distortion type_id="opencv-matrix">
  <rows>5</rows>
  <cols>1</cols>
  <dt>d</dt>
  <data>
    -4.4013430929637429e-002 -1.1965526013186709e-002
    -8.6009185550299223e-004 3.5107086019087613e-005
    2.2370656290682970e-002</data></distortion>
<extrinsic type_id="opencv-matrix">
  <rows>2</rows>
  <cols>3</cols>
  <dt>d</dt>
  <data>
    1.9325957672261140e-002 2.9406928861904845e-002
    -1.3972914292070636e-002 -7.0747479076213679e+001
    -1.6333143311740773e+002 5.0868125470187073e+002</data></extrinsic>
</opencv_storage>
```


Figure 13 Projector calibration XML output file

Generated Point Cloud

This chapter provides test data from the DLP Structured Light SDK for structured light pattern decoding and point cloud generation. The structured light module generates patterns to determine which projector rays are intersecting with the scanned object and the geometry module finds the intersection between the projector and camera optical rays to generate a depth-map and point-cloud.

To calibrate the system, the following procedure is used:

1. Calibrate the camera and system
2. From main menu of software, select “4: Setup structured light and prepare projector”
3. From main menu of software, select “5: Perform scan”

The following images show the camera captures of the projected structured light patterns:

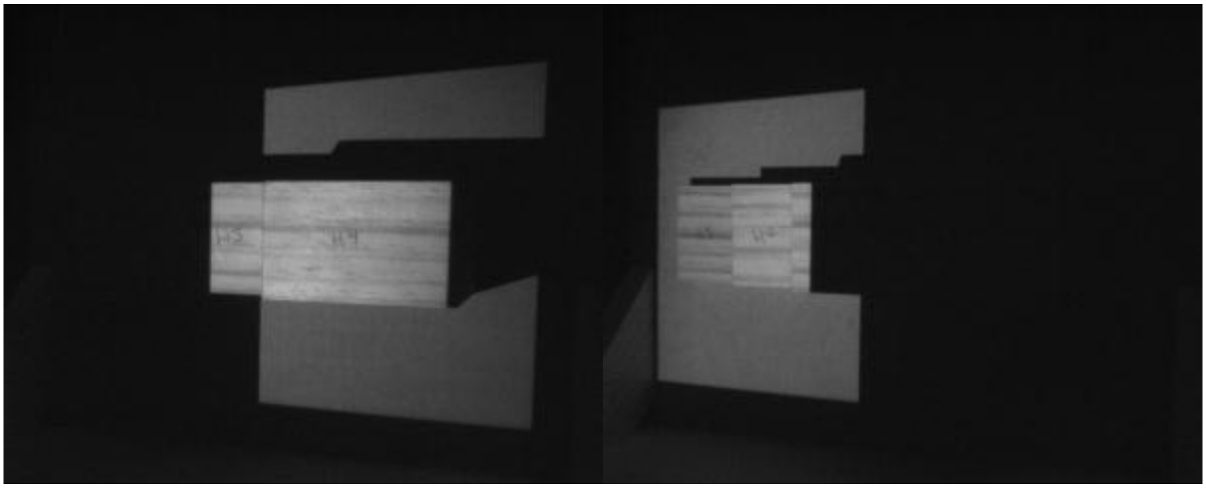

Figure 14 Non-inverted and inverted vertical gray code pattern 1 capture

Figure 15 Non-inverted and inverted vertical gray code pattern 2 capture

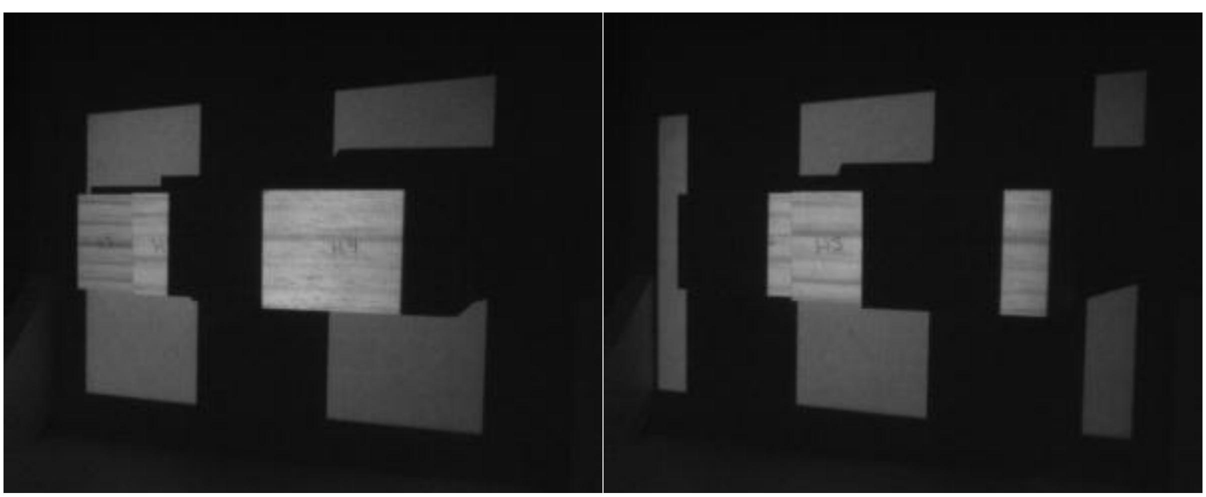

Figure 16 Non-inverted and inverted vertical gray code pattern 3 capture

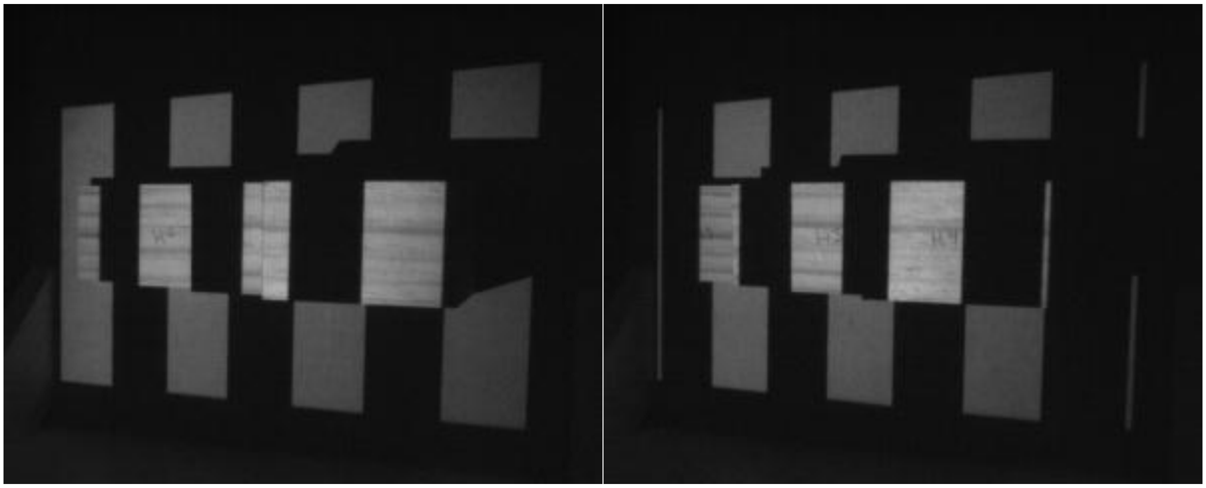

Figure 17 Non-inverted and inverted vertical gray code pattern 4 capture

Figure 18 Non-inverted and inverted vertical gray code pattern 5 capture

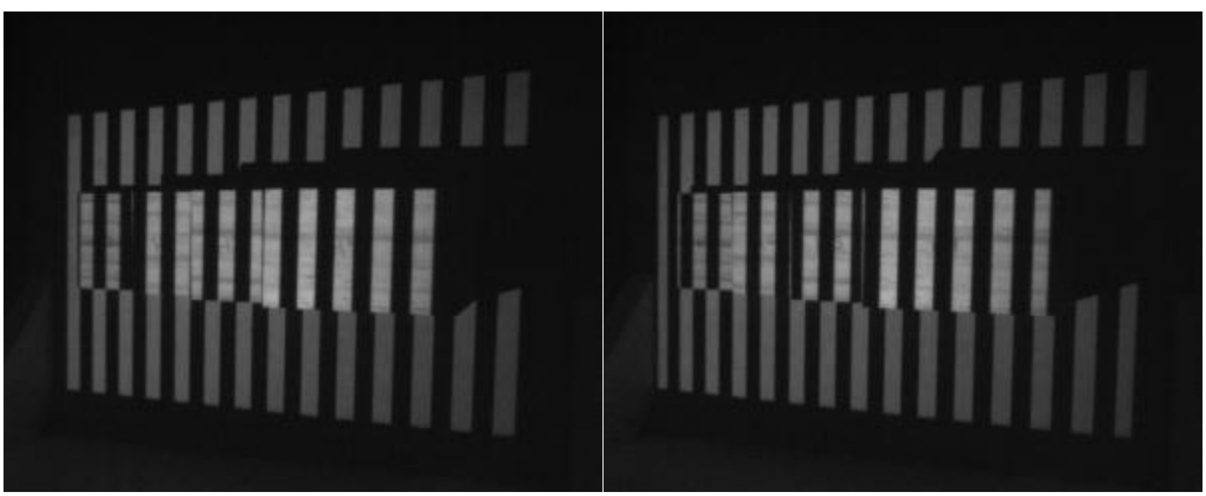

Figure 19 Non-inverted and inverted vertical gray code pattern 6 capture

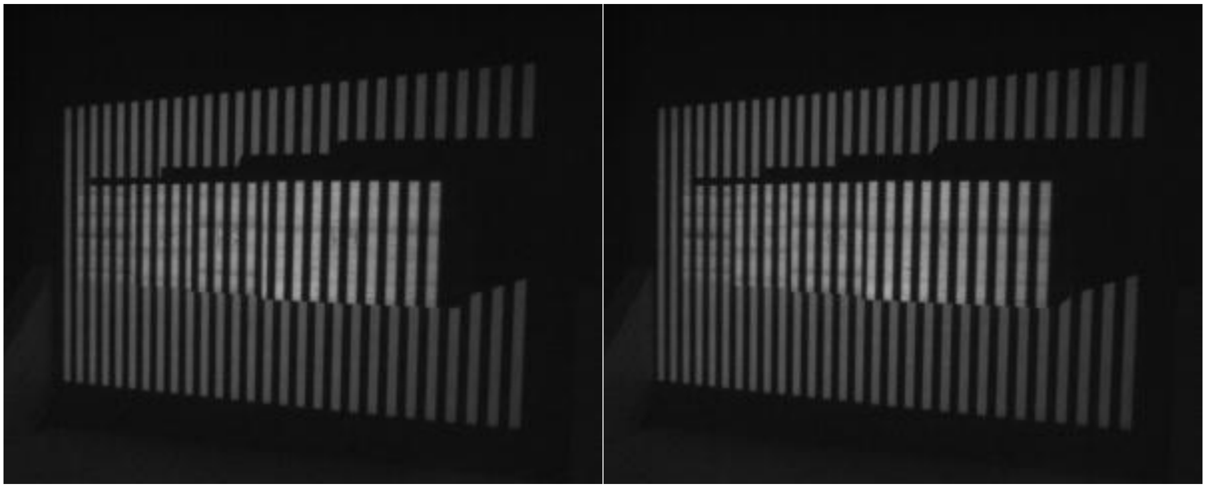

Figure 20 Non-inverted and inverted vertical gray code pattern 7 capture

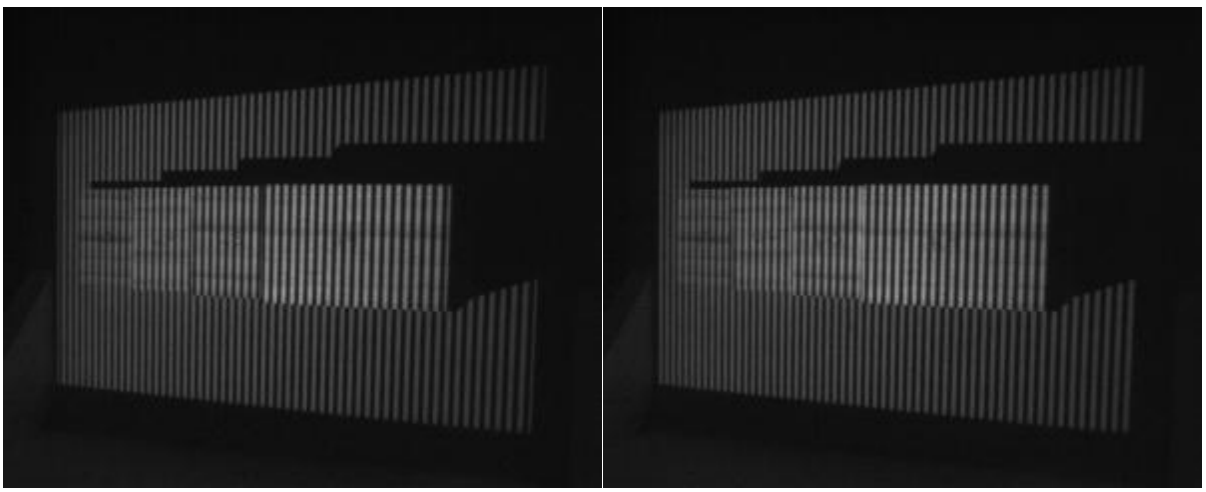

Figure 21 Non-inverted and inverted vertical gray code pattern 8 capture

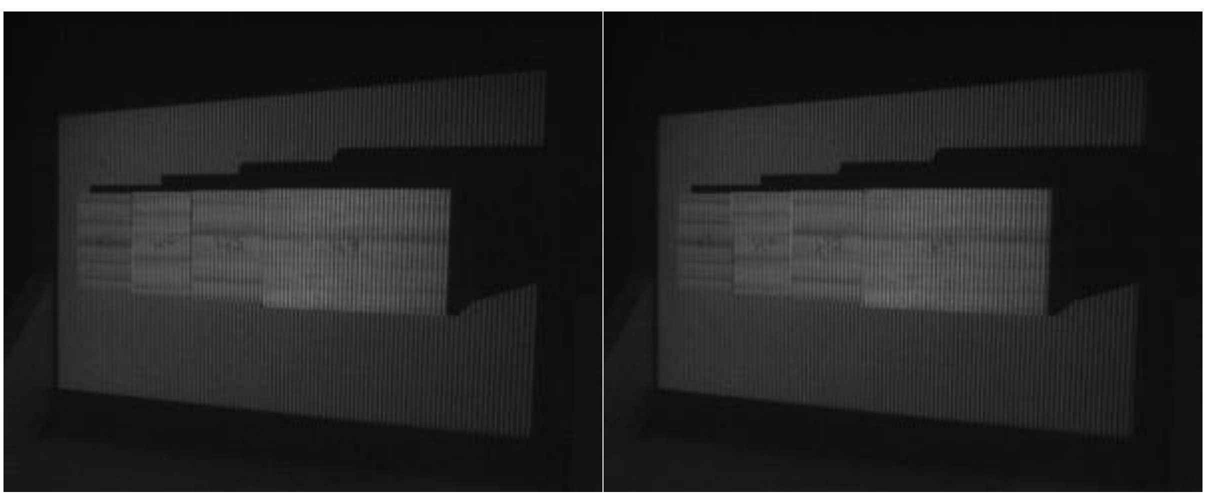

Figure 22 Non-inverted and inverted vertical gray code pattern 9 capture

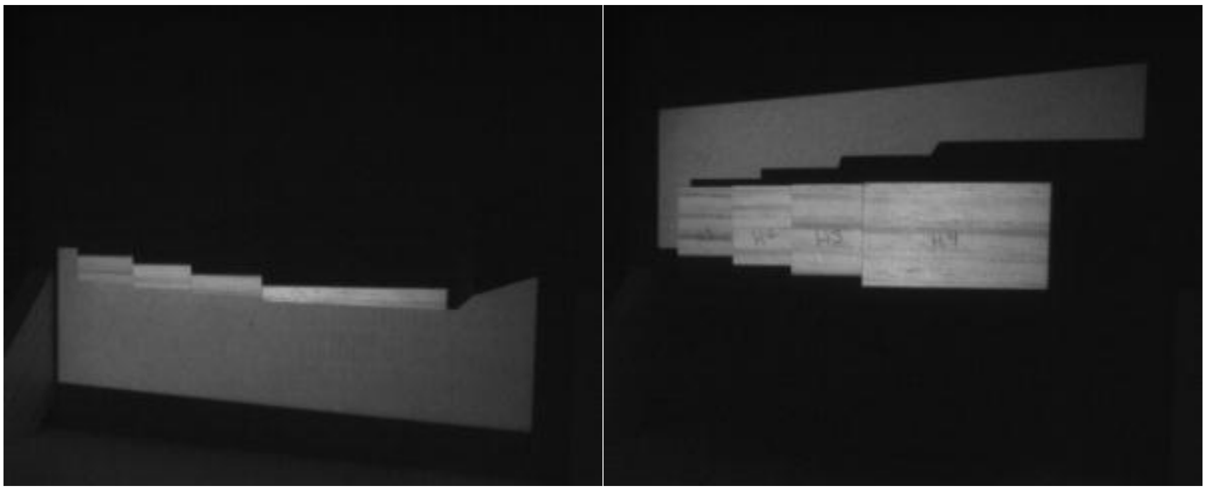

Figure 23 Non-inverted and inverted horizontal gray code pattern 1 capture

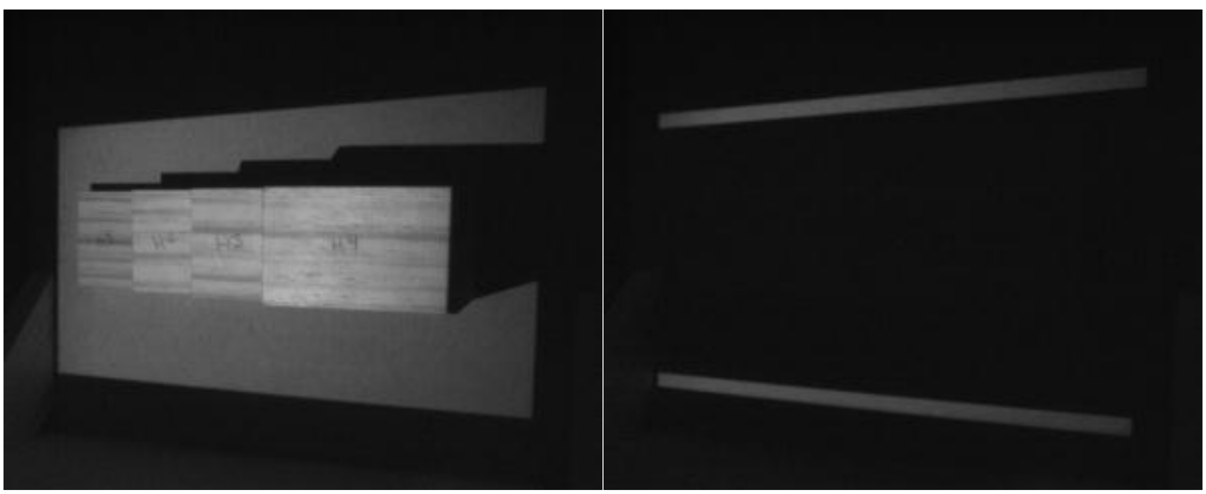

Figure 24 Non-inverted and inverted horizontal gray code pattern 2 capture

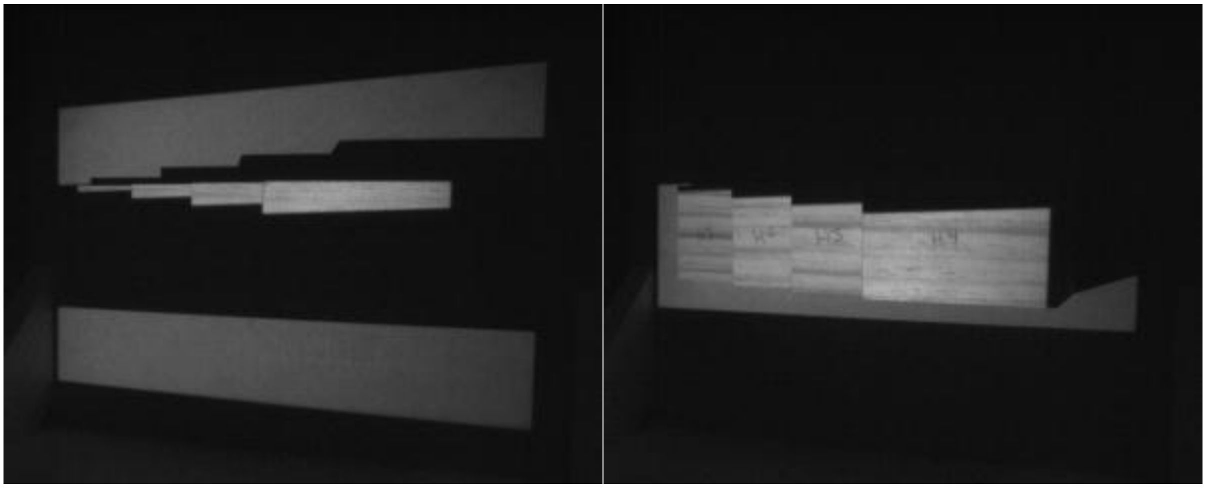

Figure 25 Non-inverted and inverted horizontal gray code pattern 3 capture

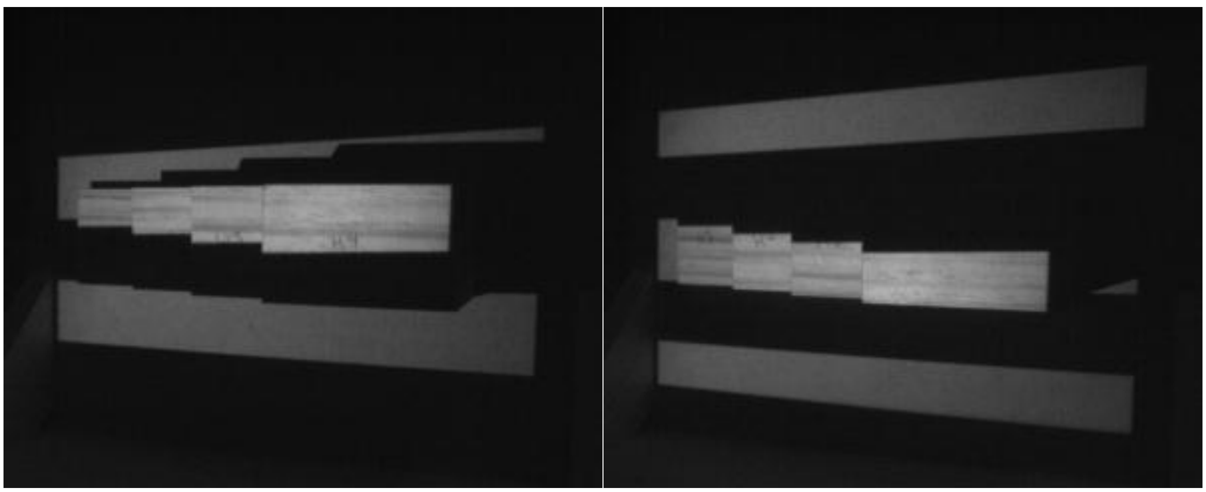

Figure 26 Non-inverted and inverted horizontal gray code pattern 4 capture

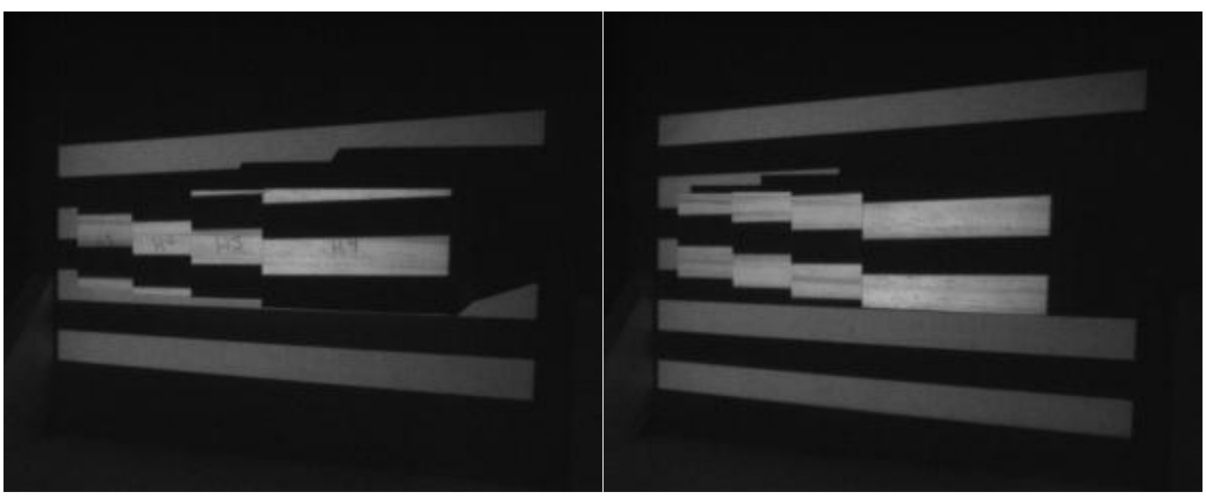

Figure 27 Non-inverted and inverted horizontal gray code pattern 5 capture

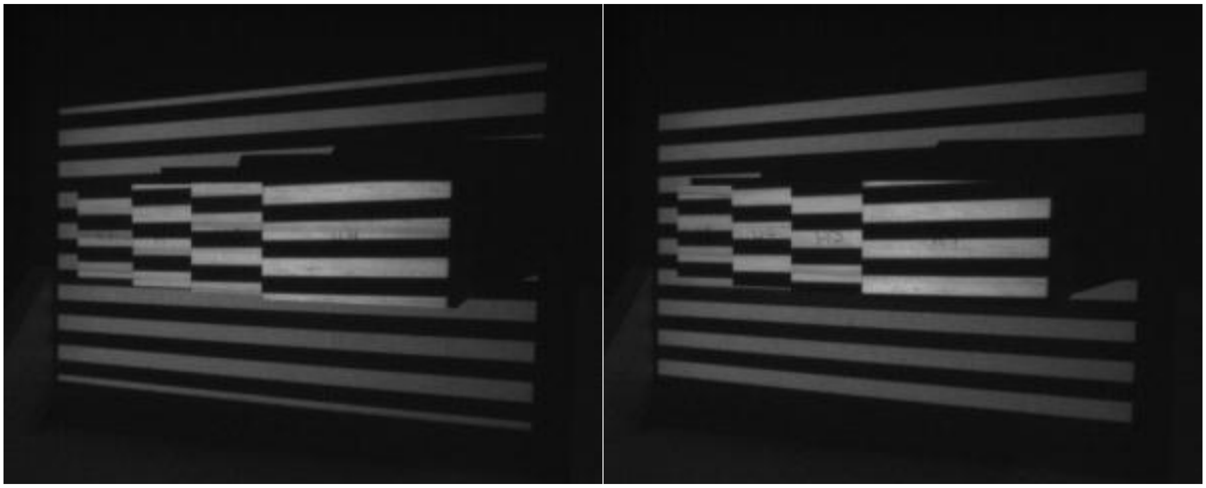

Figure 28 Non-inverted and inverted horizontal gray code pattern 6 capture

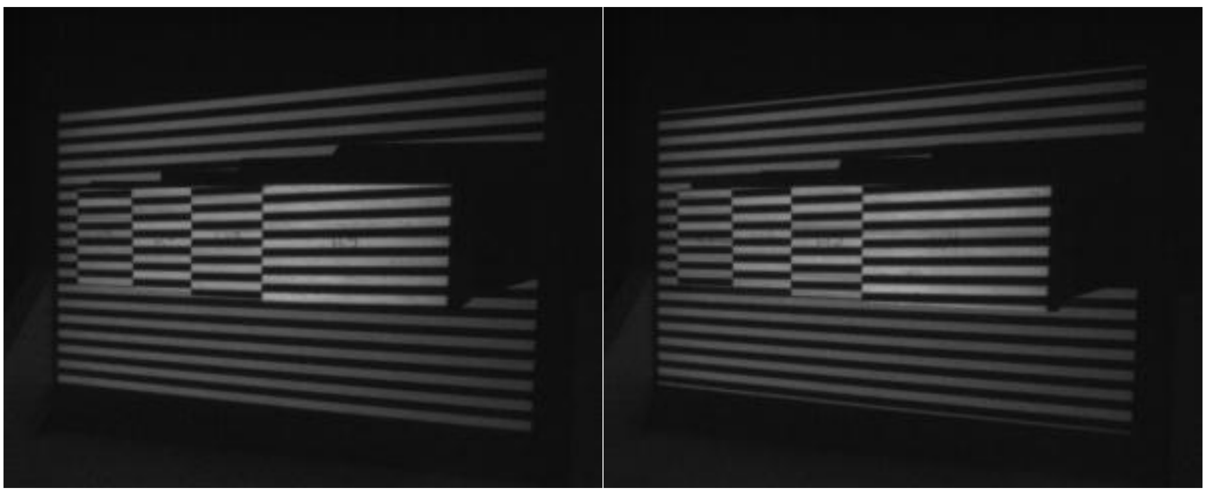

Figure 29 Non-inverted and inverted horizontal gray code pattern 7 capture

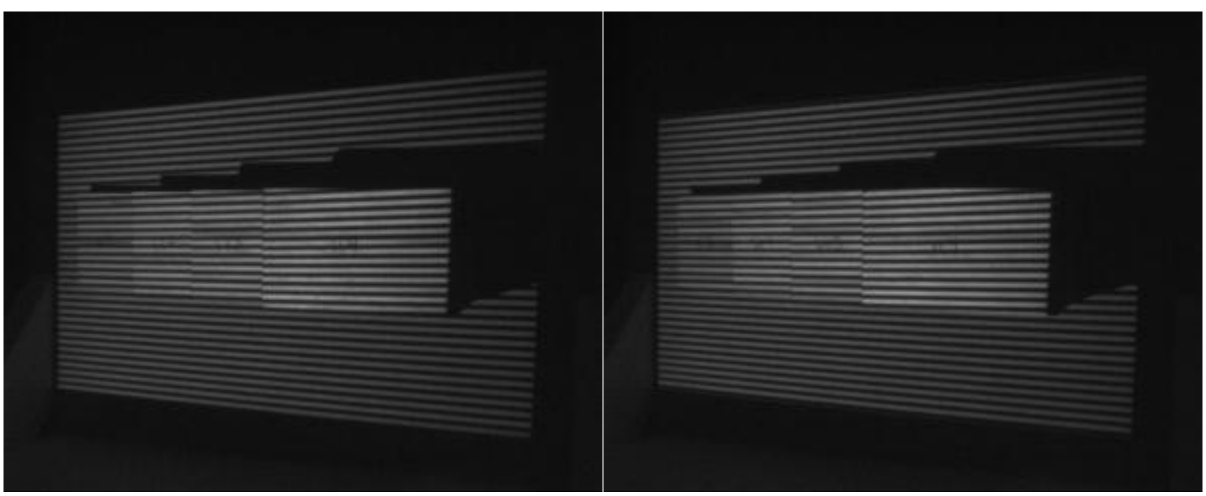

Figure 30 Non-inverted and inverted horizontal gray code pattern 8 capture

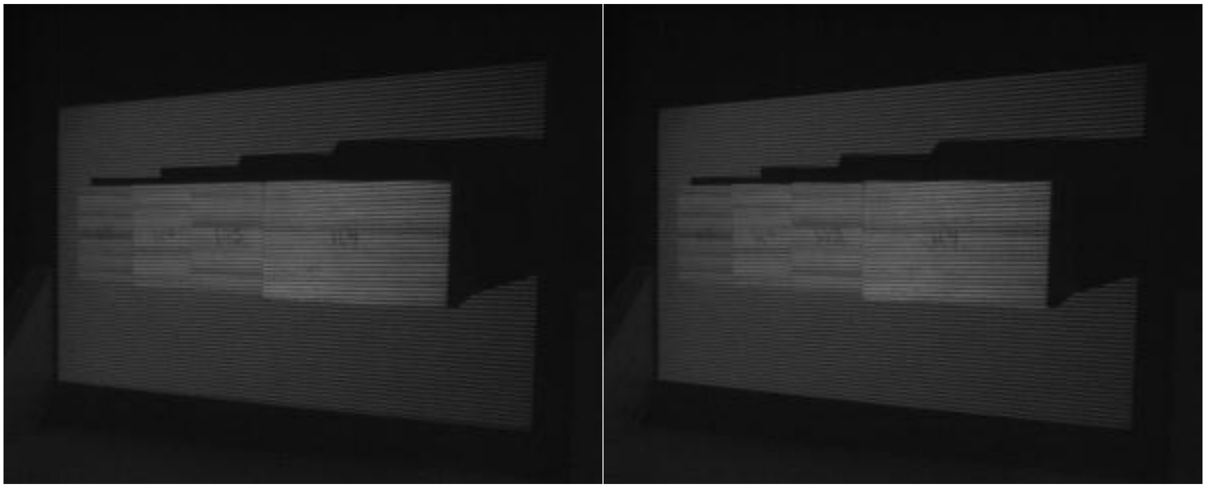

Figure 31 Non-inverted and inverted horizontal gray code pattern 9 capture

The following images show the depth-map and various views of the generated point cloud:

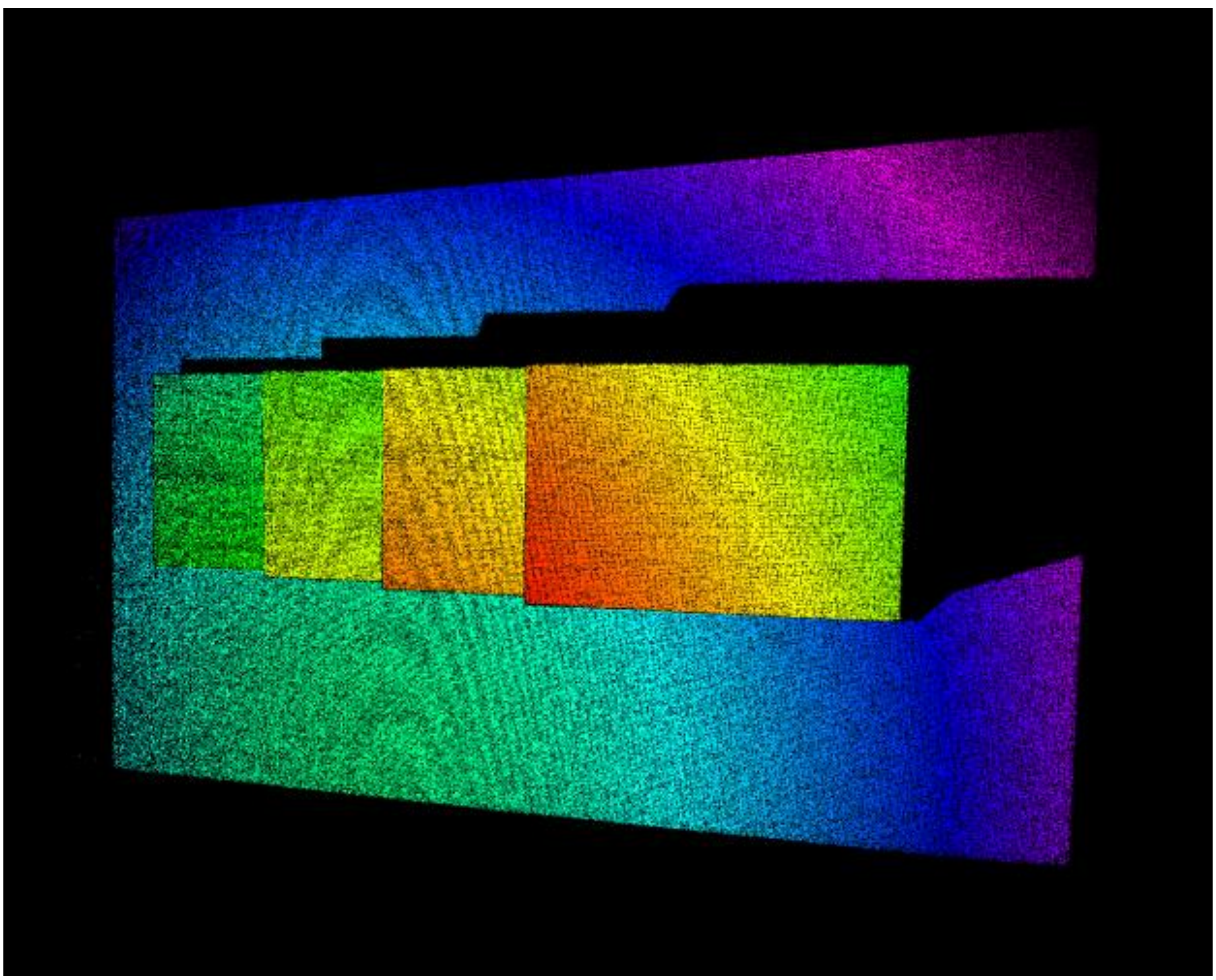

Figure 32 Depth-map of object from 3D scan

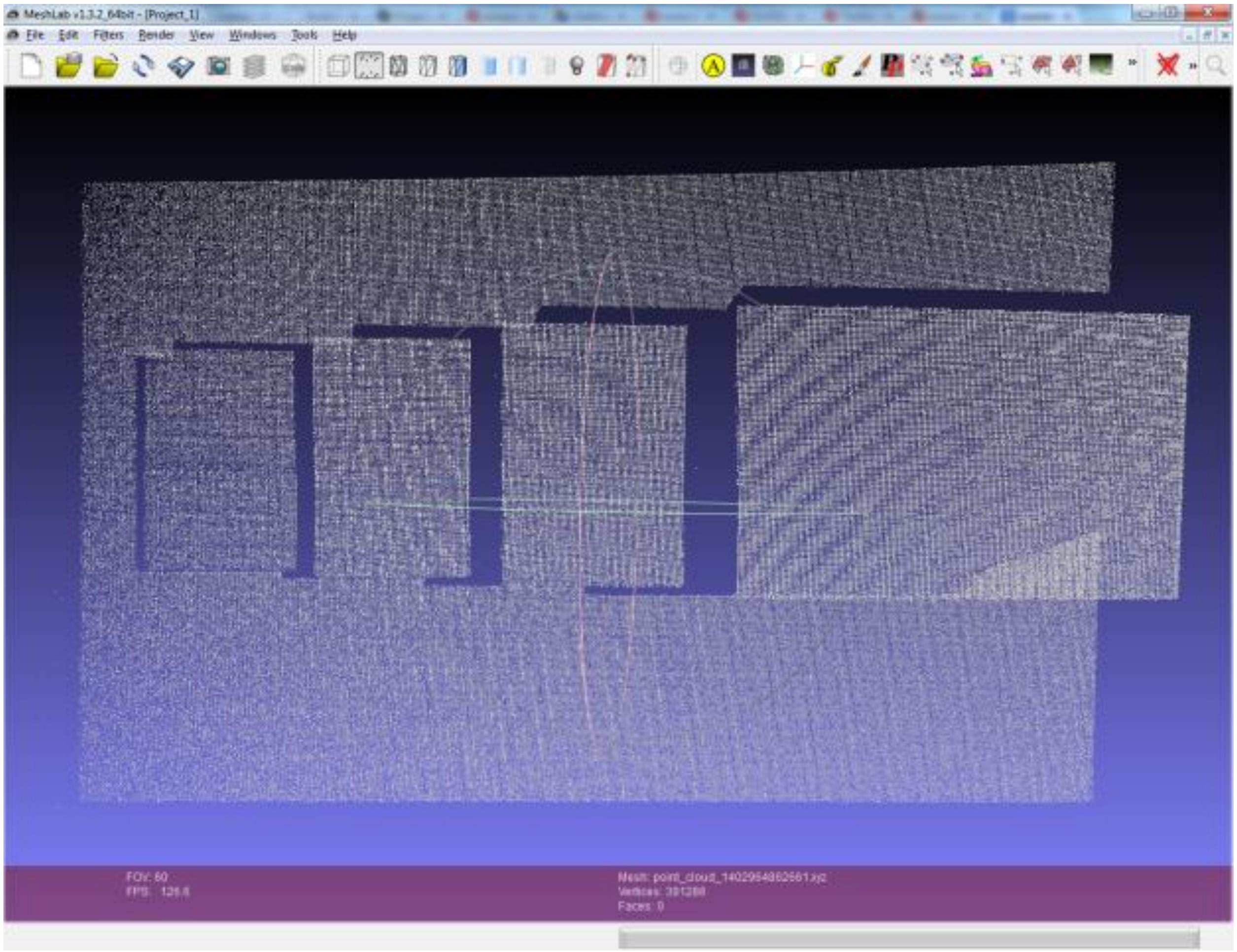

Figure 33 Front view of point-cloud from 3D scan

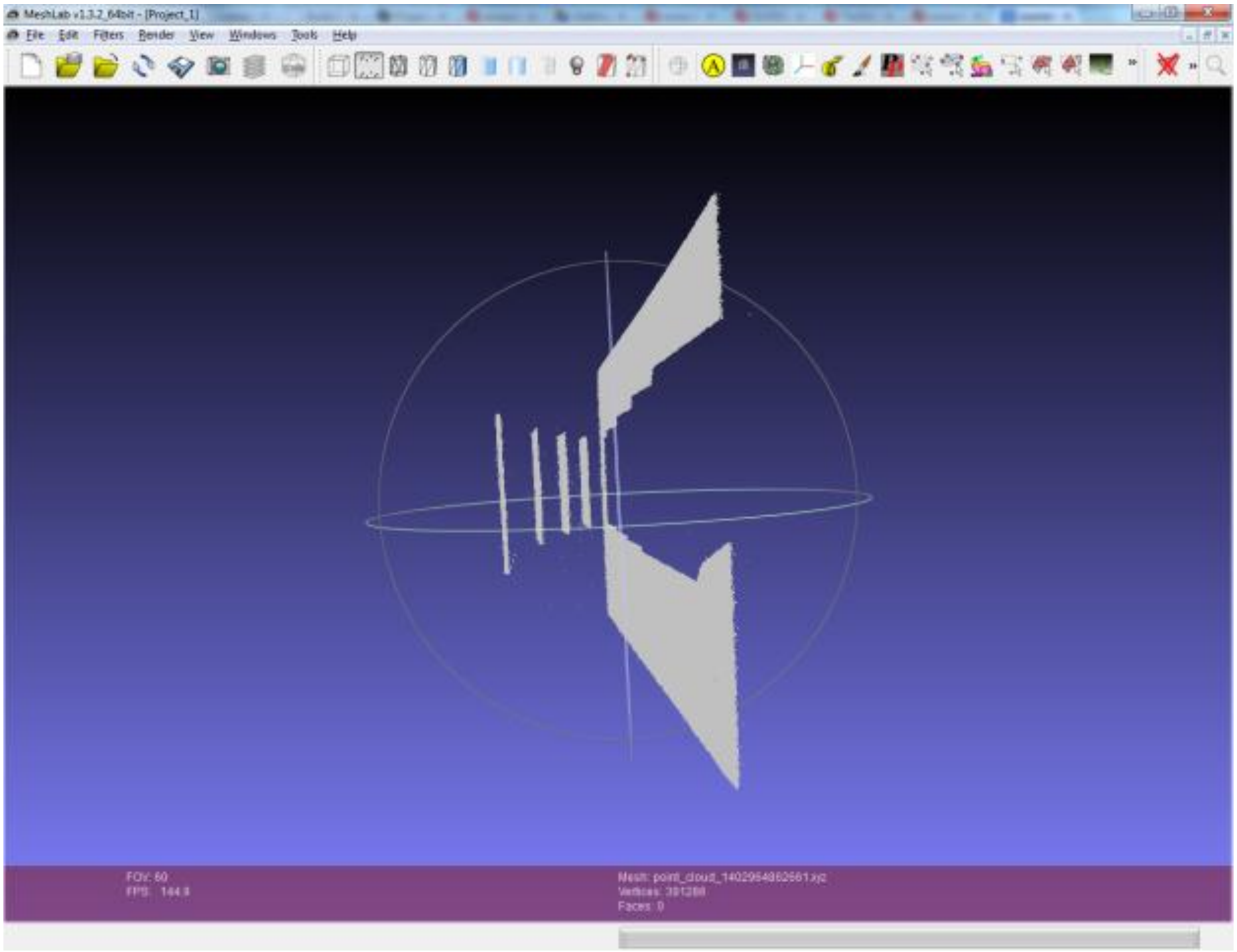

Figure 34 Side view of point-cloud from 3D scan

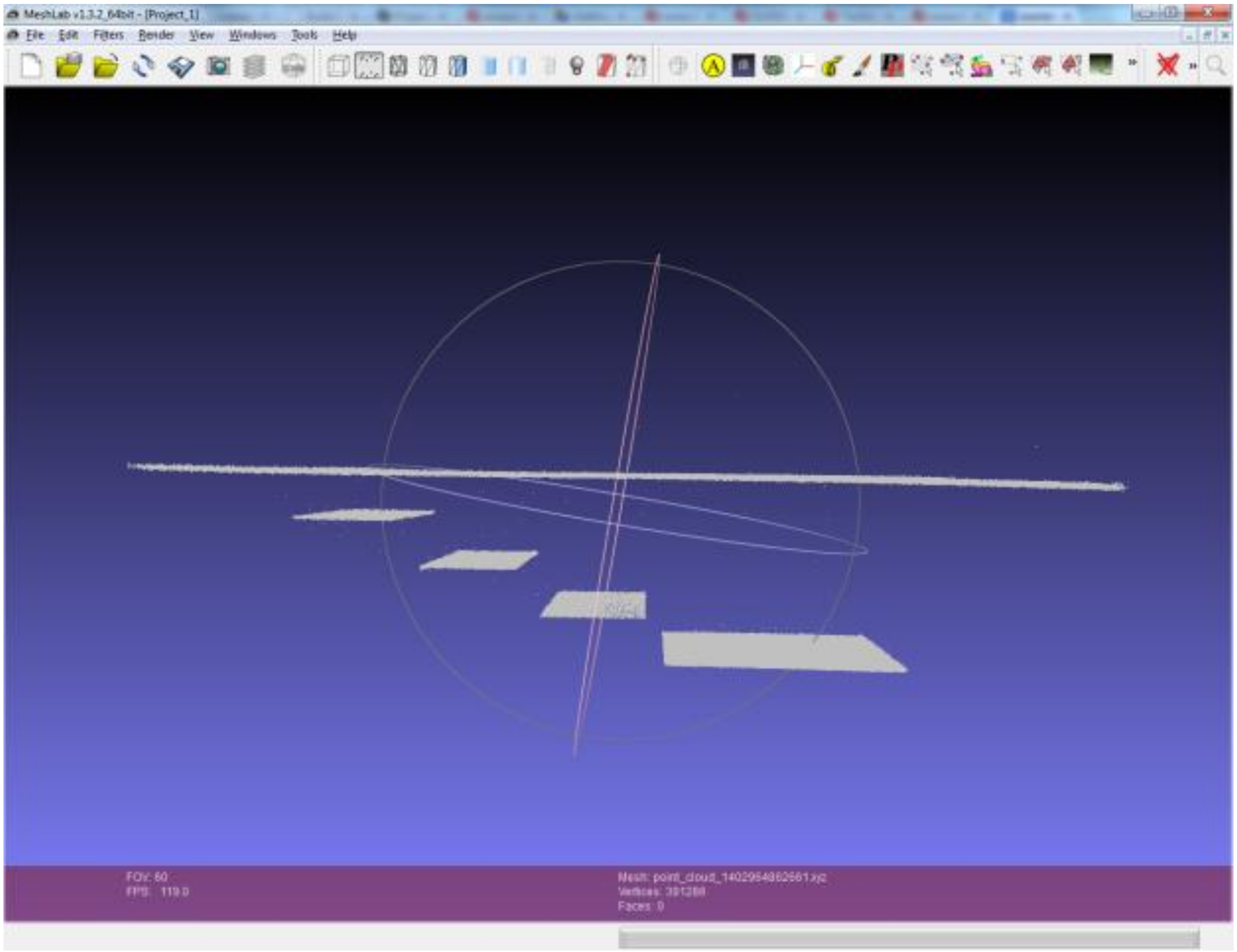

Figure 35 Top view of point-cloud from 3D scan

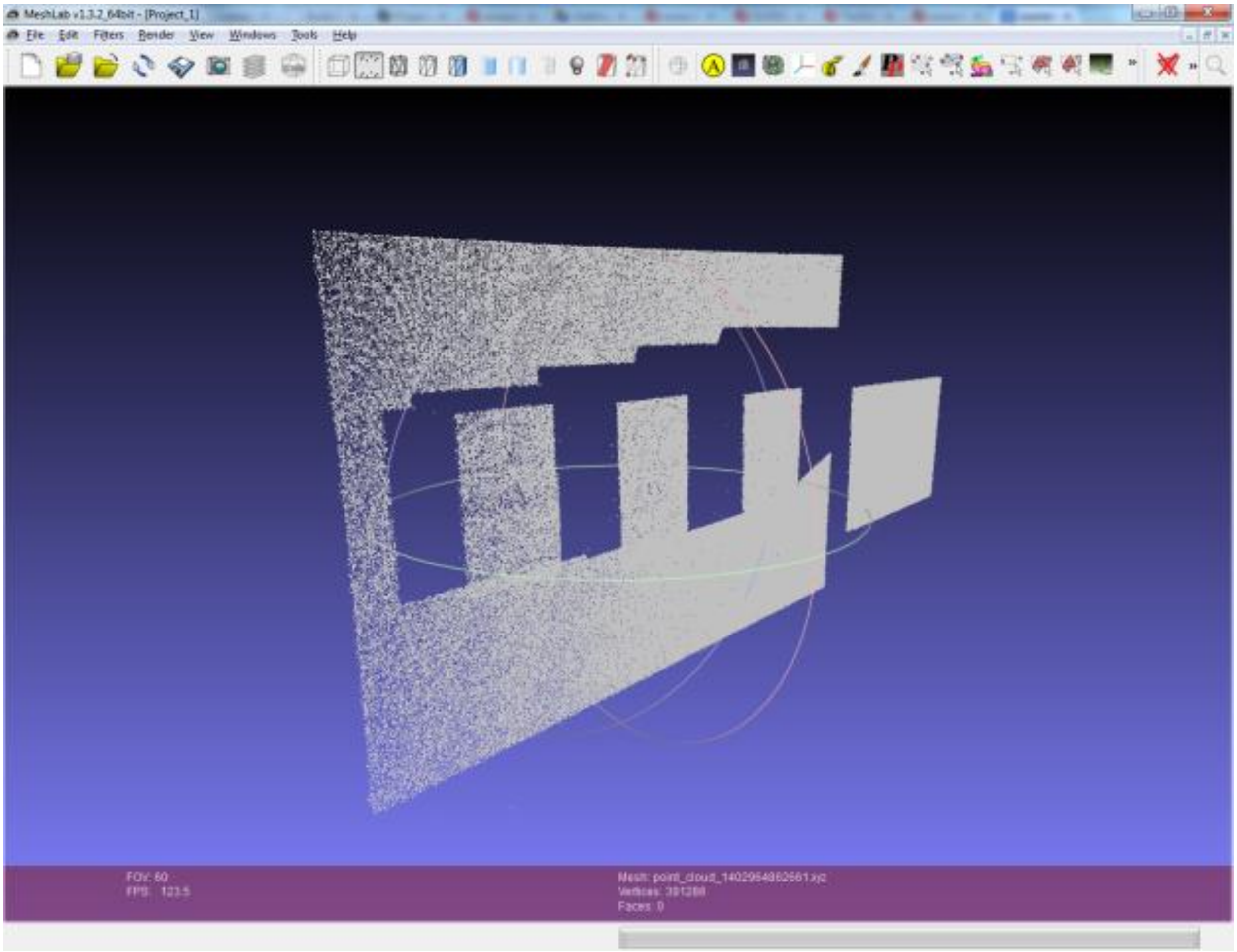

Figure 36 Isometric view of point-cloud from 3D scan