

# TERRESTRIAL LIDAR FOR INDUSTRIAL METROLOGY APPLICATIONS: MODELLING, ENHANCEMENT AND RECONSTRUCTION

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Commission V, WG V/1

**KEY WORDS:** Lidar, Industrial, Scanning, Accuracy Enhancement, Reconstruction

## **ABSTRACT:**

Time-of-flight laser scanners represent an emerging technology for capturing 3D data. They use a pulsed laser with a high data acquisition rate. The reflectance of surface varies by properties of materials and is an issue when scanning. Laboratory experiments were conducted using different types of piping materials. This paper examines the effects of scanning with various types of materials, which are used in industrial piping system, in terms of measurement accuracy. Maximum coverage angles of point clouds and diameters for each pipe are measured and compared. Application of a masking tape and dulling spray was found to be effective in improving the accuracy of the data.

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## **1. INTRODUCTION**

Over the past several years, ground-based laser scanners have been introduced to the area of industrial applications such as chemical refinery plants and piping network construction. Light Detection and Ranging (LiDAR) scanners measure the range by pulsed laser. They often employ a high-speed rotating mirror to scan the laser over surface of objects.

Industrial piping systems, in general, consist of piping networks, which are made of various types of materials such as metals, steels, and PVC. The reflectance of the surface materials is one of the major factors to be considered in order to capture sufficient 3D data with a desired accuracy.

This paper presents experimental tests of different piping materials and accuracy analyses based on coverage angles of point clouds and diameter measurements. Different types of media were applied to objects' surfaces and examined to see if there was any improvement in the coverage angles and measurement accuracies.

## **2. LABORATORY EXPERIMENT**

### **2.1 Objectives**

The purpose of these experiments is to examine the effects of reflecting surface materials on laser scanning measurements. Reflectance of surface material is an issue for scanning, and data capture is often impossible without sufficient laser beam reflection, which is sensed by a photo-detector in a scanner head. One of the major factors in the acquisition of field data is the reflectance of materials. Therefore, it is worthwhile to examine reflectance properties in order to acquire appropriate laser scanning data.

The scanner (CyraX 2500) uses a pulsed time-of-flight (TOF) laser with a wavelength of 532nm and the energy of laser mainly depends on physical and geometric factors. Physical factors can include the material's magnetic permeability and electric permittivity. Geometric factors

include the angle of incidence and roughness of the surface. In this experiment, geometric factors were studied by angle coverage observations and the alteration of the physical factors was studied by application of different media on the surfaces.

For this project, the study of various materials is limited to specific materials used in industrial piping system such as brass, cast iron, aluminum, stainless steel, and PVC. However, extended studies of different materials can be conducted for other applications such as bricks, concrete, and wooden objects, which are major component of buildings and urban structures.

Observation of coverage angles and measurement of diameters were carried out for different materials based on their point-cloud data. Dulling spray and masking tape are applied to the surfaces as a roughness enhancing medium and the effects will be studied to see if there is any improvement in the data accuracy. The results of the study can improve the overall accuracy of a measurement process for applications related to industrial piping systems.

### **2.2 Experiment Set-up**

The test field was set up in an enclosed area and the model space volume was approximately 2m x 2m x 2m. The test field was illuminated using normal fluorescent lights without any natural light source. The lighting conditions were uniform for the entire test and the temperature and humidity were normal in the room. There was no interference in the air such as wind or dust during the measurement process.

Different types of circular-cylindrical materials were mounted on the table and they were aluminum, brass, cast iron, galvanized iron, stainless steel, glass, and PVC. The diameters of each object were measured by a digital caliper with the precision of 0.01mm. The model space and testing objects is shown in Figure 1.

To quantify and analyze the effects of reflectance on different surface materials, the scanner stations were set up approximately 2.9m from the model space. The distance from a laser scanner to the scanning objects was between 2.5 to 3.3m. The maximum coverage angle between two tangent points on a cylindrical object can, theoretically, be between 176° to 178° on

a diameter of 30mm to 100mm within an observation distance of 2.9m. The scanning resolution was approximately 1.7mrad (i.e., 5mm point spacing at a range of 3m) and the number of points was between 30,000 and 220,000.

The first set of scanning data was acquired from stations 1, 2, and 3 and the second set (stations 4, 5, and 6) was conducted after applying a dulling spray on the surfaces.

Two scans were captured at each scanner station; the first one had an approximate sample spacing of 5.0 mm x 5.0mm and the second was 2.0mm x 2.0mm. The first scan was sparse using a fast scan to examine the point cloud data to see if it was reliable. This took less than a minute. For the purpose of the experiment, the second data set involved a sample spacing of 2.0mm x 2.0mm. This set was dense and the data acquisition time was less than 3 minutes per scan.

### 3. Analysis of Coverage Angles

#### 3.1 Observation of Coverage Angles on different surface materials

Point-clouds data from scanning stations 1 to 6 were selected to observe coverage angles on the different surfaces. From the scanning data, each cylindrical object was closely examined and unnecessary points were eliminated for cylinder fitting. By use of 'fit-to-cloud' option, cylinders were formed for each object and their diameters were determined. Point-clouds data were exported into text and "dxf" file formats to observe the coverage angles and to conduct residual analyses.

Based on a diameter measurement obtained by a caliper, a circle was drawn and fit into imported point-clouds data. Two lines were constructed by connecting the center of circle and one of the points, which represents the point on the surface. The coverage angle was observed by intersecting two lines. As shown in Figure 2, small squares in red and yellow are represented point-clouds on the surface and circles and lines are drawn in blue and three locations were arbitrarily selected, then coverage angles were measured. From three observations the maximum value was selected and calculated its percentage of coverage (i.e. 360° is the total coverage of cylindrical object).

The diagram of maximum coverage angles for each object is schematically shown in Figure 3. In the case of PVC and stainless steel, the coverage angles are 62.19° and 59.63°, which represent very poor percentage coverage of 17.3% and 16.6%, respectively. The cylinder fitting process with these point-clouds was not possible due to a limited coverage area. In the case of brass and ceramic, the coverage angles were observed at 165.13° (45.9%) and 126.49° (35.1%), respectively (see Table 1). From the experiment, it can be concluded that the percentage of coverage angle should be at least 20%, but 30% is recommended, in order to fit a cylinder model properly to point-clouds.

The coverage angles of point cloud in PVC and stainless steel were less than 20°, which was not useful to model objects properly due to a lack of data points. In the case of PVC pipes, the colour of the surface, which was black, was also one of the factors that degraded the point cloud data.

Sufficient reflecting signal is a key factor for capturing proper point data from field measurements. Since the energy of the reflected pulse depends on physical properties of surface material it is worth to investigate if any types of media could

improve surface reflectance without degrading accuracy. An application of chalk dust or a light coat of emulsion has been introduced to increase reflectance of material. In this experiment, a dulling spray and masking tape were applied as a medium for altering surface properties.

#### 3.2 Application of the Dulling Spray

In order to acquire enough coverage point-clouds with reliable accuracy, increasing the reflectance would be the first method to be applied. A dulling spray was applied on the area of the surface except brass and ceramic objects, which had enough coverage angles. The thin clear coat was formed on the surface and the coat was transparent. The advantages of this application are 1) easy and fast application, 2) easily removable by rubbing with or without water, 3) no effect on most materials and, 4) no effect on measurement due to its thin clear coating. Dulling spray was applied on the bottom half of the objects to compare the differences with "as-is" condition.

A short period time was necessary for the spray to completely dry. Once replaced, the object scanning process proceeded under the same laboratory conditions as described in the experiment setup.

From the point clouds, three observations were made to measure a coverage angle within distribution of points on surfaces. The impact of spray was quite extensive in terms of increased coverage angles, which is critical to fit objects during the modelling process. The reflectance difference after applying dulling spray, as clearly shown in Figure 4, can be observed visually in the point cloud data. The bottom half of the area was coated with the dulling spray and had a wider coverage angle than areas without spray by a factor of 61%.

The increase in percentage coverage was within the range of 40% to 61% and the modeling process was now possible with PVC and stainless steel, which had less than 20% coverage angle without the spray.

The thin sprayed coat was easily removed by rubbing with a cloth two days after the spray application was applied, and no indication of g surface change was observed. However, heat and high temperature of piping objects might be problematic in practical field applications such as pipes in industrial process plants. It should be handled carefully where open flame or sparks exist. The effects of heat and high temperature have not been studied at this time.

#### 3.3 Application of Masking Tapes

Masking taping applied to the surface is another technique to increase the coverage angles on certain surfaces such as aluminum. The use of masking tape can alter the geometric factors such as surface roughness and the angle of incidence.

To increase the surface roughness on an aluminum foil surface masking tape was wrapped around the top half of cylinder and scanning points were acquired as shown in Figure 5. A set of scattered red points appear on the left side of aluminum surface and most of area is blacked out, which also can be seen as shadow effects in other areas. The result indicates that the laser beam did not return to the scanner head, which means the laser energy was scattered due to the very shiny and smooth (textureless) surface.

The point-clouds on masking taped area are shown with yellow and green colors while it is mainly red in aluminum surface area. Aluminum or galvanized steel is widely used for insulation of piping system and the application of

masking tape is feasible where the surface of pipe is smooth and low temperatures exist. It is relatively simple to apply masking tape. However, high temperature or surface roughness (e.g., rusted surfaces) might be a barrier to employing this technique.

#### 4. 3D MODELLING PROCESS

Three sets of scanning data were joined using a cloud-based registration method, which was introduced recently (Fall, 2002). Unlike in control/tie point-based registration, the registration can be done with points without setting out control targets around model space. This application can not only eliminate the time and cost for setting artificial targets but also reduce the difficulties of setting up targets on or around hardly accessible area. Each scan set is registered with minimum of three common points. These points can be located anywhere, but an edge of an object or very distinctive points should be chosen to track them easily in the other scan sets. The resulting scanning cloud mosaic captures a part of the table and piping objects.

To model each pipe point-clouds of each object was separated by selecting window and “cleaning points” was necessary to eliminate unnecessary points, which can be mainly noise and points of adjacent object such as a table in this experiment.

After point-clouds were selected the fitting cylinder was constructed. The diameter of cylinders was determined based on fitting object. Diameter of each object is compared with ‘true’ diameter measured by a caliper in 0.01mm. In the case of galvanized iron, ceramic, and aluminum the measured values from scanning data were within 2 to 4 mm differences, which were compared with ‘true’ diameter. However, the difference was 17mm with 38mm PVC pipe, and this was unacceptable.

#### 5. Conclusions

According to the observation of coverage angles, PVC and stainless steel have the smallest coverage angles while brass and ceramic pipes have much wider angles. In order to form a model properly at least 20 to 25% of coverage angle is recommended.

The effects of dulling spray application were quite distinguishable and the results showed 50% to 60% increases in coverage angles of point clouds compared to the “as-is” condition. Masking tape was tested on the aluminum surface and the area of scanning point clouds was increased. As a result, the accuracy of the measurement of an object was improved. The procedure of applying these media was relatively simple and efficient in an industrial environment, and their application is reliable for object measurements and modeling processes.

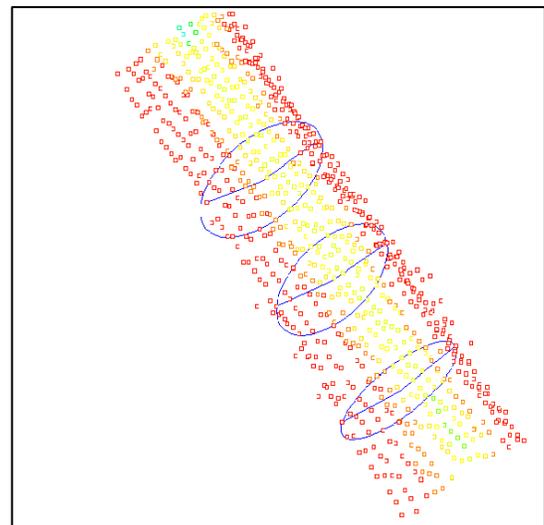
The diameter measurements of piping objects based on 3D model fitting showed the measurements were close to the ‘true value’ in the case of ceramic, aluminum, and galvanized iron. However, measurements on some materials such as PVC and Stainless steel were unacceptable range.

#### 6. References

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Figure 1 Test field setup for Reflectance Experiment



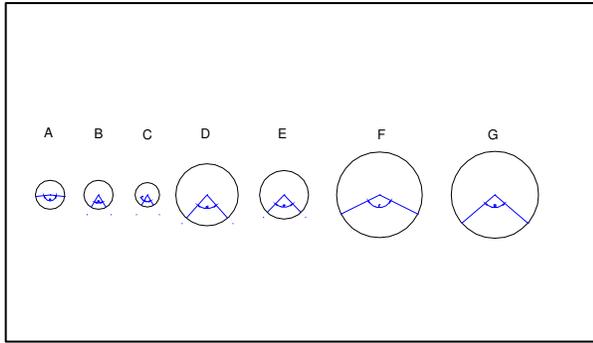


Figure 3. Diagram of maximum coverage angles

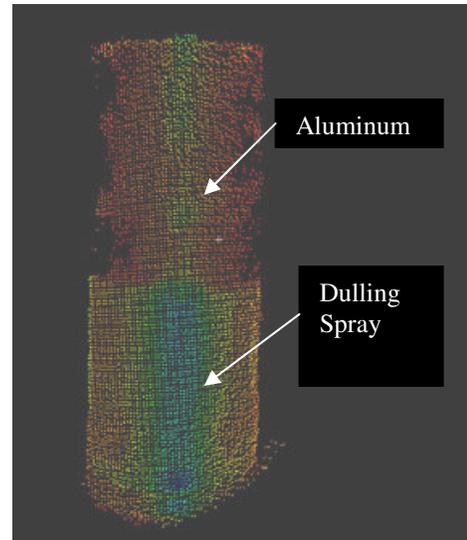


Figure 4. Point cloud showing with and without an application of dulling spray

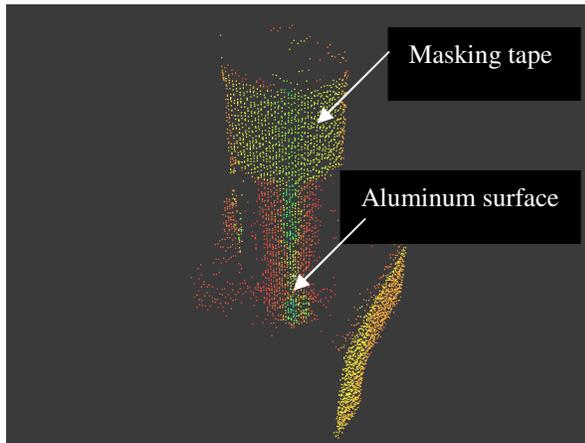


Figure 5. Point cloud showing with and without a masking tape

Pipe	Surface Materials		Coverage Angle Observations (degree)				Coverage (%)	Increase (%)
			1	2	3	MAX. Angle		
A	Brass	N/A	158.20	165.13	153.15	165.13	45.87	N/A
B	PVC	As Is	62.19	57.14	52.79	62.19	17.28	50.4
		Sprayed	115.12	98.94	123.51	123.51	34.31	
C	Stainless Steel	As Is	56.17	59.63	45.22	59.63	16.56	39.5
		Sprayed	134.91	151.16	140.59	151.16	41.99	
D	Galvanized Iron	As Is	83.08	67.95	69.55	83.08	23.08	60.8
		Sprayed	134.79	126.65	136.62	136.62	37.95	
E	Steel	As Is	82.47	86.46	81.45	86.46	24.02	56.4
		Sprayed	145.50	153.32	149.94	153.32	42.59	
F	Ceramic	N/A	123.71	126.49	124.01	126.49	35.14	N/A
G	Aluminum	As Is	93.11	98.64	95.24	98.64	27.40	61.0
		Sprayed	156.91	161.66	153.08	161.66	44.91	

Table 1. Observations of Coverage Angles with Dulling spray