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3D Reconstruction of Point Clouds and Solid Models from LiDAR and Digital Stereo Images

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Abstract **–**One of the fastest 3D data acquisition methods is LiDAR scanning technology. By using LiDAR scanners, 3D point clouds of the scanned scene are obtained easily. Although the scanning phase is fast, the meaningful and effective 3D visualization of the scene requires the raw point cloud data to be processed in advanced levels. This paper aims at explaining those processing steps and comparison of the LiDAR technology to the state of the art methods. For this purpose, a building point clouds data obtained by a terrestrial LiDAR scanner was used. This paper explains the registration of point clouds data, its underlying concepts, mathematical models as well as the free - open source libraries to be used to perform these operations. Despite the remarkable achievements in LiDAR technology and data processing, it is still a relatively young subject and would likely change its course rather quickly in the near future.

Keywords *–LiDAR, Registration, Point clouds data, Visualization, Terrestrial*

I. Introduction

LiDAR technology is probably the most significant technology introduced in mainstream topographic mapping in the last decade. The main advantage of the technique is that it provides a direct method for 3D data collection. Furthermore, it is highly accurate because of the millimeter - and centimeter - level laser ranging accuracy and precise sensor platform orientation supported by an integrated position and orientation systems (POS) when required[1]. Unlike the traditional photogrammetric methods, LiDAR directly collects an accurately geo-referenced set of dense point clouds, which can be almost directly used in basic applications. However, the full exploitation of LiDAR's potentials and capabilities are challenges for new data processing methods that are fundamentally different from the one used in basic applications. Over the last decade, there have been many significant developments in this field, mainly resulting from multidisciplinary research, including computer vision, computer graphics, electrical engineering, and photogrammetry.
Although there have been many studies and applications since introduction of LiDAR, a comprehensive compilation is still missing. The main purpose of this paper is to present a manual to the LiDAR users / applications as well as describing the problem of registration and fusion tasks of the LiDAR data.

II. Materials and Method

In this research, the Faro laser scanner was used. We used small white balls and papers as control points. There are four instruments of LiDAR technology. These are;

1) Profiling LiDAR
2) Small- footprint LiDAR
3) Large-footprint LiDAR and
4) Ground Based LiDAR

In this paper, the method used is Ground - Based LiDAR. A case study is on a governmental building which has now been privatized. The private owner wishes to change the building into a hotel. The building is located at Gayrettepe in İstanbul. İstanbul is divided into two sections which includes Europe and Asia. Gayrettepe is in the European side of İstanbul.

Registration of Coordinate Frames and the Data Sets

Registration is a pre-processing step required if multiple scans are taken to capture a scene. It aligns and combines multiple data sets into one complete 3D cloud. Several approaches have been developed to address the registration task. One of the most popular algorithms is the Iterative Closest Point (ICP) algorithm[2] which requires an initial rough alignment between two clouds and then iteratively searches for point matches to solve for a transformation. Other methods utilize targets [3] or feature points [4] to determine the required transformations. However, registration is now a tool that is commonly available in laser manufacturer software programs, and hence, it was not a focus of this paper alone. Consider a simple concept of registration below;

Combine small overlapping images into single large image.

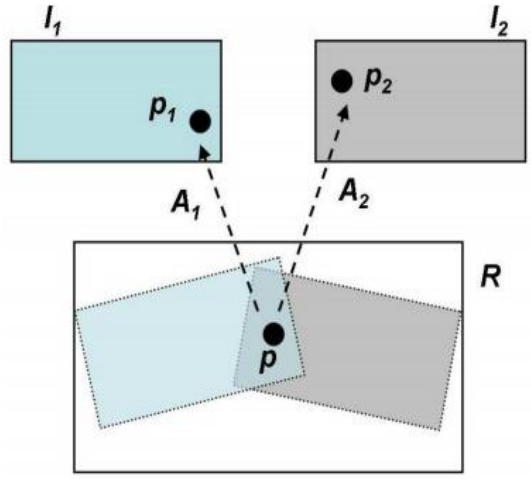


Fig 1. Simple registration

From fig 1 above;

Suppose that the matrices $\mathbf{A_1}$ and $\mathbf{A_2}$ are known.
They specify the transformation between the output image R and the input images I_1 and I_2, respectively.
For each pixel p in R, do:

- compute: $\mathbf{p_1} = \mathbf{A_1}\,\mathbf{p}$ and $\mathbf{p_2} = \mathbf{A_2}\,\mathbf{p}$.
- If both $\mathbf{p_1}$ and $\mathbf{p_2}$ fall outside of I_1 and I_2, respectively, then R(**p**) = default no data color, say black.
- If both $\mathbf{p_1}$ and $\mathbf{p_2}$ fall inside of I_1 and I_2, respectively, then R(**p**) = blending of $I_1(\mathbf{p_1})$ and $I_2(\mathbf{p_2})$.
- Otherwise, only one of $\mathbf{p_1}$ or $\mathbf{p_2}$ falls inside I_1 or I_2. So, R(**p**) = $I_1(\mathbf{p_1})$ or R(**p**) = $I_2(\mathbf{p_2})$, as appropriate.

Most objects are big enough to be scanned from one position, as obstacles may prevent scanning of some sides, and so there is always a need to do different scans form distinct positions or viewpoints in scanning projects. This will lead to a number of different scans of the object with different coordinate systems, and these different scans are needed to set together in one scan with a common coordinate system for the whole object.

The process of setting a common scan of an object from scans with different coordinate systems is known as registration or aligning.

Registration is the process that involves the alignment of two or more-point data sets in different coordinate systems to each other, resulting into one coordinate system for both.

In the laser scanning systems, the process is achieved by transforming the coordinate system of one of the point sets to the other point set coordinate system by applying specific translations and rotations in means of rigid body transformations (six degrees of freedom), where the shape and size are preserved (Scale factor is unity – orthogonal transformation).

Thus, in principle, registration is considered as coordinate transformation problem that involves translations and rotations, and the problem is a sub-group of the general affine coordinate transformation, solved in the manner of similarity or rigid body transformation.

This coordinate transformation problem can be represented as a least square problem which is solved by minimizing the square of error as in equation (2)[5].

$$\boldsymbol{a_i} = \boldsymbol{R}\,\boldsymbol{b_i} + \boldsymbol{t} \tag{1}$$

$$\varepsilon^2 = \sum_{i=1}^{n} \|\boldsymbol{a_i} - (\boldsymbol{R}\,\boldsymbol{b_i} + \boldsymbol{t})\|^2 \tag{2}$$

where $\boldsymbol{a_i}$, $\boldsymbol{b_i}$ are coordinate vectors formed by the corresponding point coordinates of points in data sets to be registered. The coordinates are relative to the coordinate systems of their own datasets respectively. $\boldsymbol{R}$ and $\boldsymbol{t}$ are rotation matrix and translation vector, respectively.

In Cartesian coordinate system, rotation in rigid body transformation is normally represented through two ways:

Euler's angle rotation representation;

Euler angels are rotation angles that applied to each axis to form the desired rotation successively. By applying these rotations about the coordinate system axes x, y and z successively, the rotation matrix **R** in (3) is obtained:

$$\boldsymbol{R} = \begin{bmatrix} cosr_y\,Cosr_z & cosr_z\,sinr_z & -sinr_y \\ -sinr_x\,sinr_y\,cosr_z + cosr_x\,sinr_z & sinr_x\,sinr_y\,sinr_z + cosr_z\,cosr_x & -sinr_x\,cosr_y \\ cosr_x\,sinr_y\,cosr_z + sinr_x\,sinr_z & -cosr_x\,sinr_y\,cosr_z + sinr_x\,cosr_z & cosr_x\,cosr_y \end{bmatrix} \tag{3}$$

Where r_x, r_y and r_z are the rotation angles about x, y, z axes respectively.

Axis and angle rotation representation;

Euler angles could suffer from gimbal lock problems when used for rotation representation; an alternative way is to represent the rotation by defining a rotation angle around a rotation axis. This is achieved in this by using quaternions and used in this paper.

To represent a rotation by an angle (θ) around a rotation axis represented by a vector $[e_1\,e_2\,e_3]^T$, the rotaion matrix $\boldsymbol{R}$ in (3) is parameterized by using the unit quaternion $[q_0, q_1, q_2, q_3]^T$ namely a 4-vector in 4D complex space. In this case the rotation matrix is obtained as;

$$\boldsymbol{R_q} = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 - q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 - q_0q_3) & q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_2q_3 - q_0q_1) \\ 2(q_1q_3 - q_0q_2) & 2(q_2q_3 - q_0q_1) & q_0^2 + q_1^2 - q_2^2 - q_3^2 \end{bmatrix} \tag{4}$$

Where,

$$q_0 = e_1 sin\left(\frac{\theta}{2}\right), q_1 = e_2 sin\left(\frac{\theta}{2}\right), q_2 = e_3 sin\left(\frac{\theta}{2}\right), q_3 = e_1 sin\left(\frac{\theta}{2}\right) \tag{5}$$

Different approaches are used for the computations of the transformation parameters; they vary between iterative and closed-form solutions. These approaches mainly differ in the representation of rotation and translation, and the used error minimizing criteria[6].

Mostly, the closed-form solutions are preferred due to their stability and the numerical solution is based on singular value decomposition (SVD) [7], [9, 10] and [11].

In SVD, the fact that the two point sets have similar distributions around their means (centroids) is used. A covariance matrix is computed between the two point sets after whitening the dataset's data. The rotation matrix and/or the rotation axes are obtained from the eigenvectors and eigenvalues of the covariance matrix. Then obtained rotation

parameters are used to compute the translation vector [12], [13] and [14].

Closed form solutions are generally superior to iterative methods, in terms of efficiency and robustness, because the latter suffer from problems of not guaranteeing convergence, becoming trapped in local minima of the error function and requiring a good starting estimate[17]. Thus, the closed forms are preferred to calculate the transformations in laser scanning software's.

In this research, the quick view of the scan building is a single scan that is not loaded and it is done in few second. However, the data is manipulated. The data at the planar view is loaded. In the 3D view, it is not limited to display the scan points of a single scan or scan point clouds, it offers combined view of all the scans and objects.



Fig 2 Quick view of the scan building



Fig 3 Planar view of the scan building

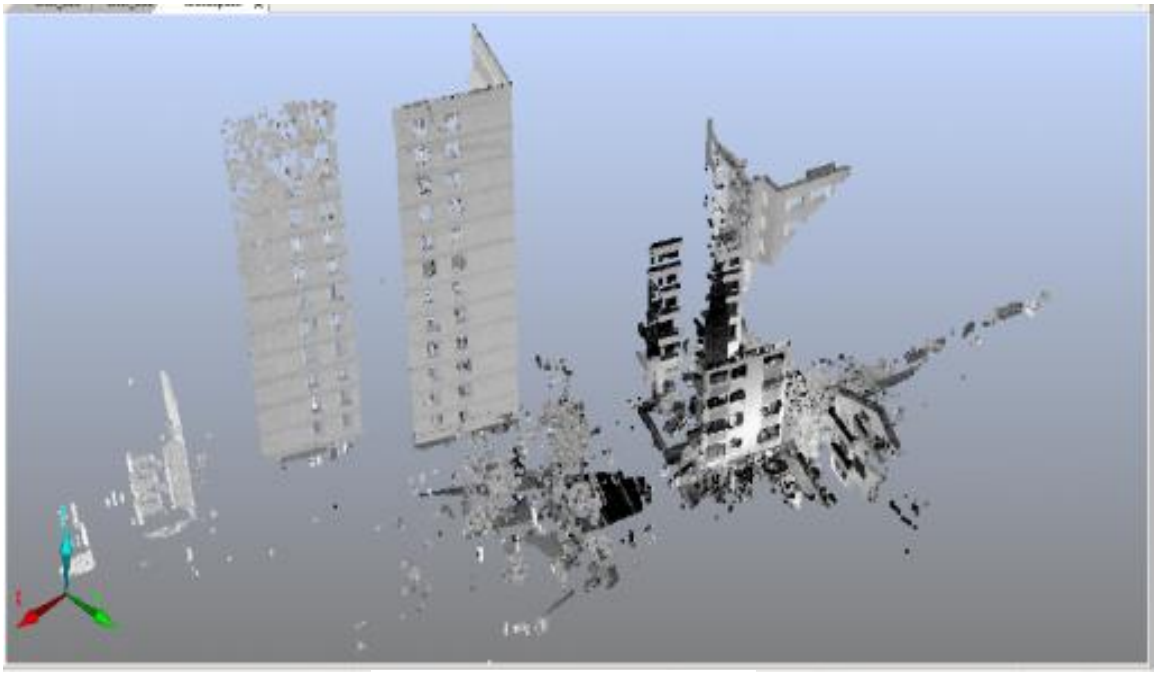


Fig 4 3D view of the scan building

Table 1. Position number and coordinates of 001

1	2	3	4	5	6	7	8
Ignore	Ignore	X coord.	Y coord.	Z coord.	Red	Green	Blue
1024	1894	-2.80080000	-0.71320000	110.11310000	188	188	188
1024	1895	-2.79990000	-0.71130000	110.11120000	187	187	187
1024	1896	-2.79500000	-0.70810000	110.10360000	144	144	144
1025	1895	-2.80320000	-0.71210000	110.11080000	162	162	162
1025	1896	-2.80490000	-0.71060000	110.11250000	186	186	186
1025	1897	-2.80600000	-0.70910000	110.11360000	166	166	166
1025	1898	-2.79920000	-0.70550000	110.10310000	122	122	122
1026	1896	-2.83740000	-0.71880000	110.15370000	119	119	119
1026	1897	-2.80970000	-0.71000000	110.11360000	164	164	164
1026	1898	-2.80970000	-0.70820000	110.11300000	166	166	166
1026	1899	-2.80420000	-0.70490000	110.10460000	115	115	115
1027	1898	-2.78350000	-0.70160000	110.07050000	88	88	88
1027	1899	-2.81430000	-0.70750000	110.11380000	126	126	126
1083	1973	-3.05260000	-0.62150000	110.11130000	123	123	123
1083	1974	-3.05070000	-0.61930000	110.10840000	175	175	175
1083	1975	-3.05170000	-0.61730000	110.10920000	192	192	192

III. RESULTS

Registration is a pre-processing step required if multiple scans are taken to capture a scene. It aligns and combines multiple datasets into one complete 3D cloud. One of the most popular algorithms is the Iterative Closest Point (ICP) algorithm which requires an initial rough alignment between two clouds and then iteratively searches for point matches to solve for a transformation. In this paper, two surfaces (007 and 008) were considered to finely do the alignment. Cloud compare was used in the transformation process.

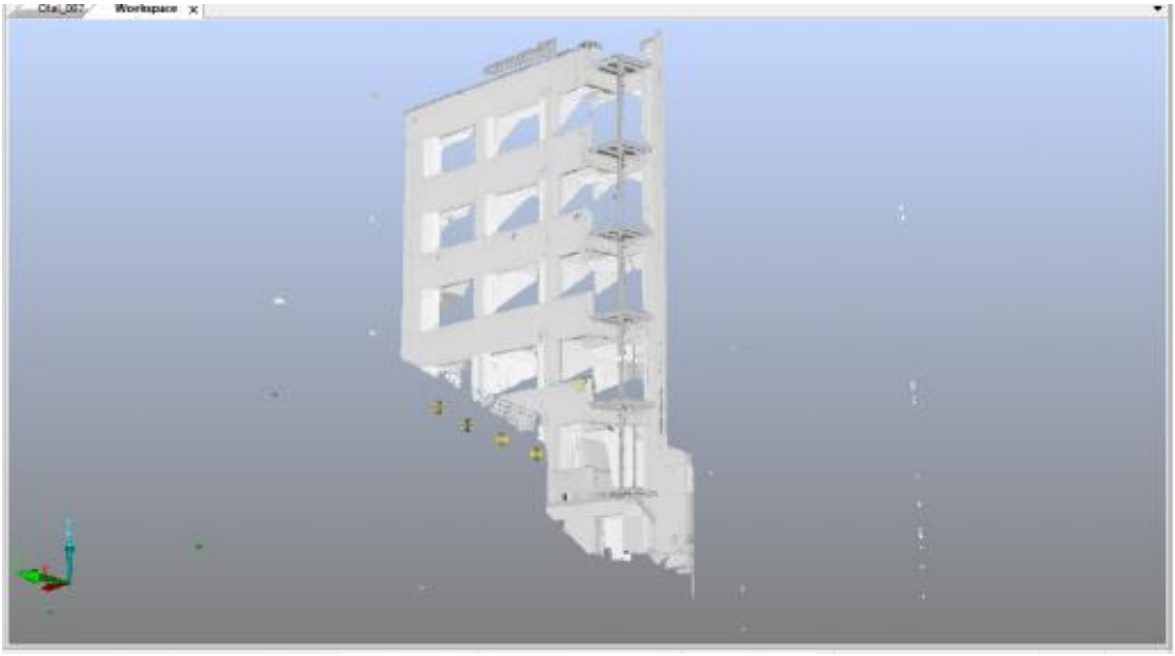


Fig 5 3D view of the scan 007 of building

Table 2. Position number and coordinates of 007

1	2	3	4	5	6	7	8
Ignore	Ignore	X coord.	Y coord.	Z coord.	Red	Green	Blue
931	18120	-31.51220000	-0.96190000	110.30360000	241	241	241
991	18136	-31.51130000	-0.90430000	110.29700000	192	192	192
1606	19268	-30.96630000	-0.17070000	110.56640000	223	223	223
2145	5274	-12.01580000	-18.77770000	141.06480000	192	192	192
2146	5274	-12.00770000	-18.78470000	141.05730000	193	193	193
2415	6146	-22.67040000	-15.07230000	124.87280000	167	167	167
2415	6147	-22.67970000	-15.06710000	124.86230000	183	183	183
2416	6144	-22.65980000	-15.07120000	124.86750000	186	186	186
2416	6145	-22.66700000	-15.06880000	124.86090000	195	195	195
2416	6146	-22.66990000	-15.07300000	124.86300000	199	199	199
2416	6147	-22.68020000	-15.06630000	124.85050000	200	200	200
2416	6148	-22.69630000	-15.05040000	124.82600000	191	191	191
2417	6140	-22.63760000	-15.06890000	124.86830000	183	183	183
2417	6141	-22.64440000	-15.06800000	124.86330000	187	187	187
2417	6142	-22.64910000	-15.07000000	124.86230000	194	194	194

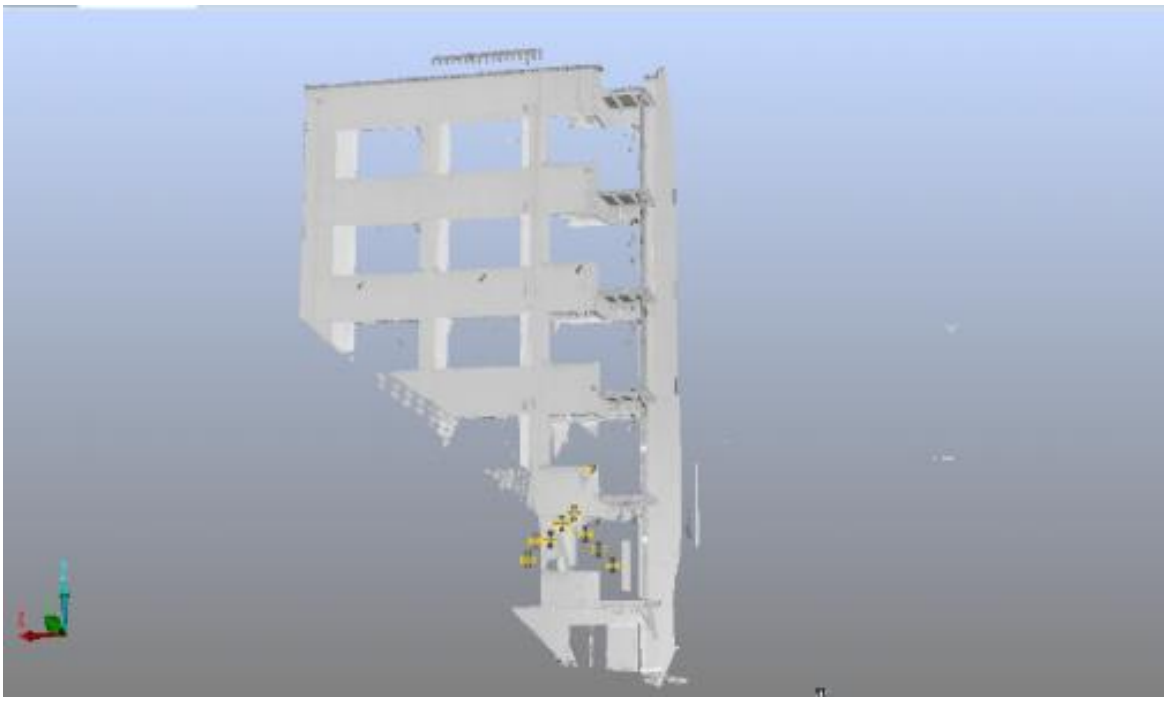


Fig 6 3D view of scan 008 of building

Table 3. Position number and coordinates of 008

1	2	3	4	5	6	7	8
Ignore	Ignore	X coord.	Y coord.	Z coord.	Red	Green	Blue
715	16717	-28.60200000	-4.21920000	111.06560000	169	169	169
716	16717	-28.60330000	-4.21830000	111.06680000	170	170	170
717	16717	-28.60430000	-4.21760000	111.06620000	174	174	174
718	16717	-28.60540000	-4.21690000	111.06630000	179	179	179
719	16717	-28.60650000	-4.21610000	111.06670000	180	180	180
720	16717	-28.60680000	-4.21590000	111.06260000	180	180	180
730	16717	-28.61640000	-4.20910000	111.05660000	179	179	179
731	16717	-28.61720000	-4.20860000	111.05530000	178	178	178
732	16717	-28.61830000	-4.20780000	111.05570000	179	179	179
733	16717	-28.61930000	-4.20710000	111.05530000	180	180	180
734	16717	-28.62000000	-4.20660000	111.05340000	183	183	183
735	16717	-28.62090000	-4.20590000	111.05240000	184	184	184
736	16717	-28.62170000	-4.20540000	111.05090000	182	182	182
737	16717	-28.62250000	-4.20480000	111.04950000	179	179	179
738	16717	-28.62340000	-4.20420000	111.04850000	177	177	177

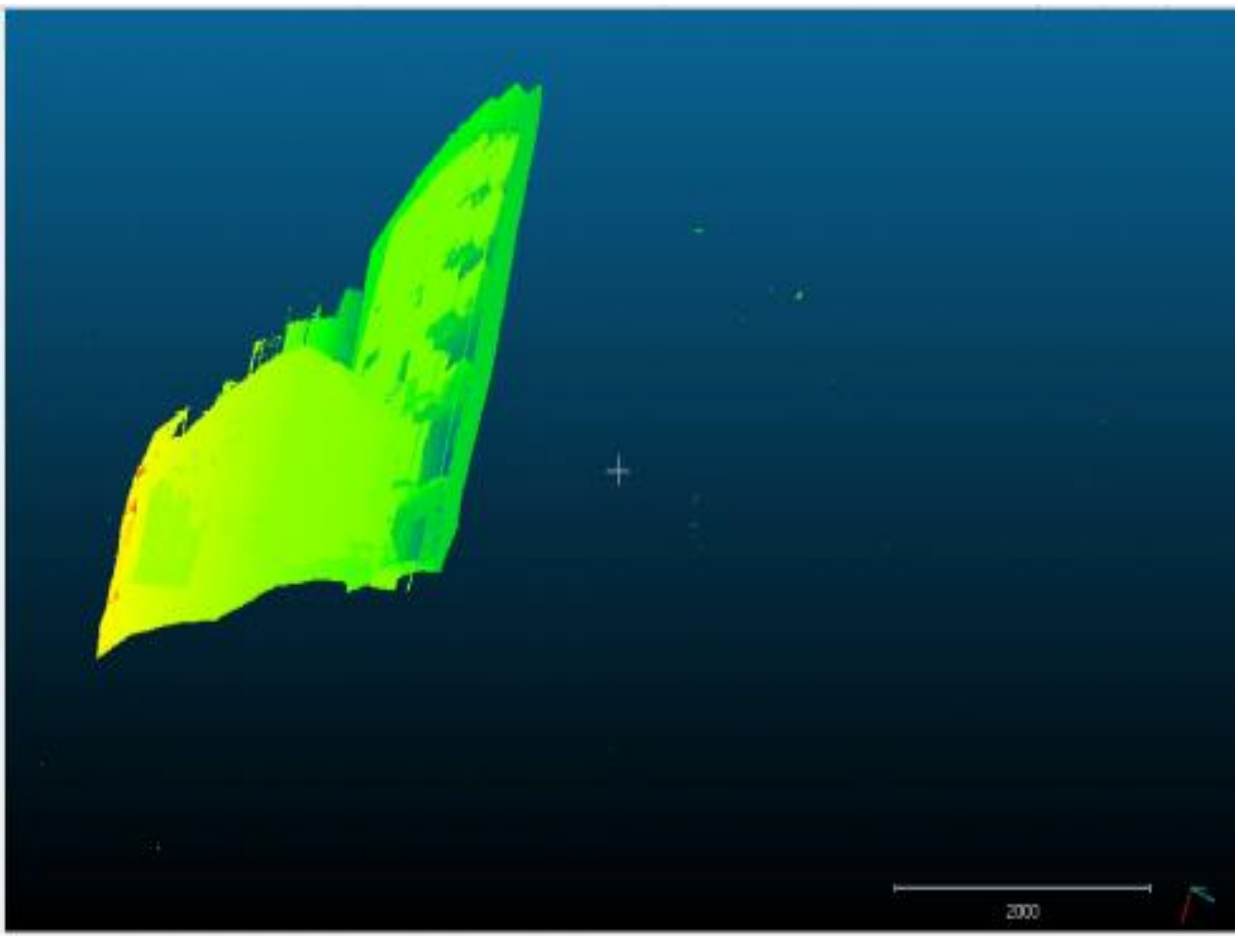


Fig 7 Finely aligned registered surfaces (007 and 008)

IV. DISCUSSION

Faro scene and cloud compare were used to help analyzed data in this paper. We were unable to overlap the picture of scan building into either 3D view, planar view or quick view. For this purpose, an efficient texture mapping routine is required. But however, since the point cloud datasets require huge amount of memory, it is still difficult and seems impossible performing the computations for all of the complete model synchronously. Novel methods are required to overcome the memory limitation problems. Cloud compare can only show partial data of scan points in all the selected surfaces. This situation also arises from the memory problems.

V. CONCLUSION

3D model has the advantage over the 2D image, because it creates a more complete picture of the object. Three-dimensional modeling is most often used in areas such as advertising and production.

Three-dimensional modeling is often used for visual presentation of products manufactured by some company. Nowadays no advertising business can work successfully without 3D modeling upscale design activities is also impossible without it.

3D simulation has many advantages. Thus, using 3D models you can hold a variety of optimization of technological processes. Through three-dimensional modeling production efficiency can be significantly increased. Three-dimensional modeling can easily be used as a substitute for natural layout.

Using three-dimensional modeling you can clearly evaluate options for joining components and assemblies. Three-

dimensional modeling in the design makes it possible to save not only time but also money. At the engineering centers you may order the creation of 3D models according to your drawings, sketches and photographs.

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