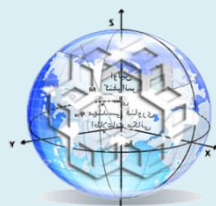


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**Introduction of a Domestic Scanner for 3D Object Modeling and its
Evaluation**

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Abstract :

Laser scanning is a widespread subject which has got many various applications in either large scale or small scale domains. Industrial, engineering, archaeological, and medical applications are just a few to name. Parto technology is one of the national laser scanner systems suitable for industrial applications. The goal of this study is to evaluate the accuracy of the proposed system based on a comparison with photogrammetry approaches. The results showed that Parto technology system can generate a 3D model with a standard deviation of 0.7 mm in comparison with common photogrammetric approaches accomplished with a 5 Megapixel camera.

Keywords: 3D modelling, laser scanner, Parto technology



1. Introduction

Laser scanning is an emerging phenomenon which is being widely used in different areas like reverse engineering [1], industry [2], forensics [3], architecture, mining, medicine, film production, and a lot of other applications, [4] and [5]. For instance, industrial laser scanning helps in precise reverse engineering, accurate quality control of manufactured pieces, precise machining and so on; designing appropriate prosthesis for patients which best fits their needs is one of usual laser scanning applications in the medical engineering field [6]. Since laser scanning is able to obtain detailed 3D information from an object without touching it, it has become a useful tool that enables archaeologists to utilize scanning for acquiring and documenting accurate 3D information about either small or large scale cultural heritages [5]. Obtained 3D information which is in point cloud format could be converted to a much larger variety of deliverables from traditional 2D drawings to detailed 3D models and animations usable in virtual tours, virtual museums, as-built maps etc.

Simplicity, safety, speed and efficiency, cost effectiveness, and easy archiving are the most important properties of laser scanners and their products. For example, one can document all objects of a museum in the most accurate way in a computer as detailed 3D textured models. Thus very different solutions for different applications appeared; terrestrial laser scanners, aerial laser scanners, and also scanners with photogrammetric basics, such as structured light and triangulation which are mostly used for desktop, small scale object scanning, are various kinds of scanners that are designed to be used in different applications.

Usual commercial scanning packages around the world, including both the scanner and the processing software, are often expensive with respect to educational budgets, or are usually customized for a specific kind of application. Also domestic requirements in the industrial sections and cultural heritage programs, made this opportunity for one of the knowledge-based companies in Iran, Parto Technology Inc., to design and build the first laser scanner in the country that is customized for scanning industrial pieces, antiquities, medical prosthesis and a large variety of small objects. The scanner was purchased for the “laser scanners laboratory” of the Geomatics engineering faculty of K.N. Toosi University of Technology in 2015, but from that time until now, no specific study has been done on it. So the authors were encouraged to work with the scanner, study the affecting parameters, extract the exact geometrical properties of the scanner, and find out that how much the nominal specifications of the scanner are close to reality.

First, hardware and software design of the system are discussed and geometry calculation concepts are proposed. After that processing steps are covered and in the final section error analysis is performed based on the true object and 3D deviation maps are derived.

2. System Design and Components

Parto Technology is an Iranian company which introduced its first scanner device about two years ago. The system is a CNC based scanner which is able to either be a laser scanner or, by replacing its head, change to a CNC milling machine. Nationality, high nominal accuracy (100 microns), and its low price are some of the P015 laser scanner advantages. On the other hand, low speed, huge size, un- user friendly software package, and difficult calibration process are its great disadvantages. In 2015, K.N.T. University of Technology purchased this laser scanner for the “Laser Scanners Laboratory”.



Fig 1. Parto Technology P015 Laser scanner

In this section different parts of the scanner are introduced and discussed.

2.1. Hardware

As mentioned earlier, one of the greatest disadvantages of the P015 is its large size. About 3m length (when board is installed), 1.5m width, and about 2m height, together with a computer to control the scanning process, a room is required for the scanner.

Three main parts shape the structure of the device. The static platform which the object is placed on it, moving panel which moves along x-axis direction, and the scanner head which moves in y- and z- axis directions and includes the optical instruments. Two kinds of step motors control the scanner movements. One of them is used to move the scanner to the initial scanning position which moves fast, and the other one is used to make small continuous motions required for scanning procedure; these motors move at about 1mm/sec. The nominal scan speed in the scanner catalog is 1cm²/sec.

Core of the scanning system is its optical head containing an HD Pro Webcam c920 for obtaining images, and four linear laser emitters to produce horizontal and vertical laser planes. Maximum distance of the head to the board is 26cm. Horizontal and vertical laser sources are 14cm and 8cm apart, respectively. Laser plane convergent point is about 7cm below the head, creating the main geometry of the scanning.

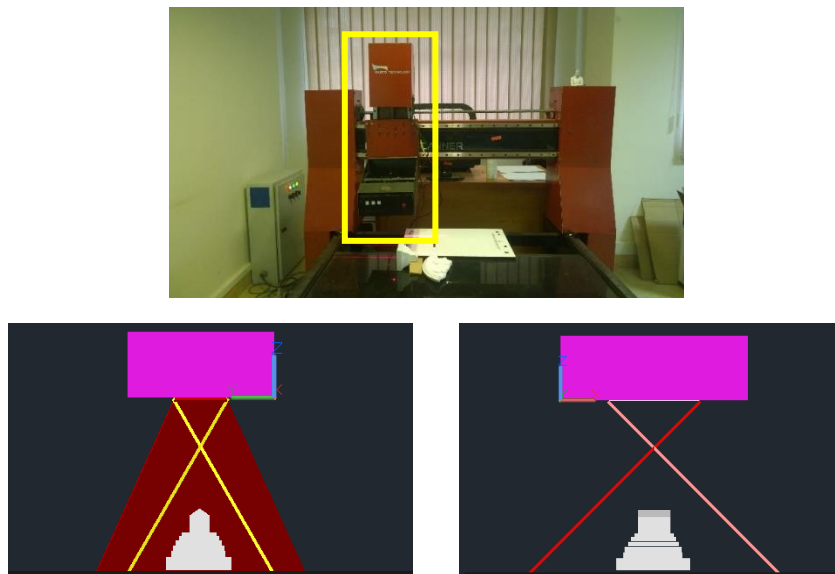


Fig 2. Top) Laser scanner head and the optics instruments, Bottom-right) Schematics of horizontal laser beams, Bottom-left) Schematics of vertical laser beams

2.2. Software

All the scanning procedure, calibration process, and device motions are controlled via a computer system. Calibration process is performed automatically through the software and the scanner calibrates itself with respect to the reference calibration board. It is not necessary to repeat the calibration process in every scan, and only once is enough for multiple scans.

Assuming that the calibration process is already performed, one can start the scanning by only knowing the size of the object. Approximate size of the object is inserted in the required fields of “scan” menu, and scan quality and overlaps are determined by the user. Based on these three parameters, software calculates the approximate scanning duration. In the second and third pages of the software, hardware communication port (COM3) and camera are selected respectively. The last thing that user should do is to press the start scan button.

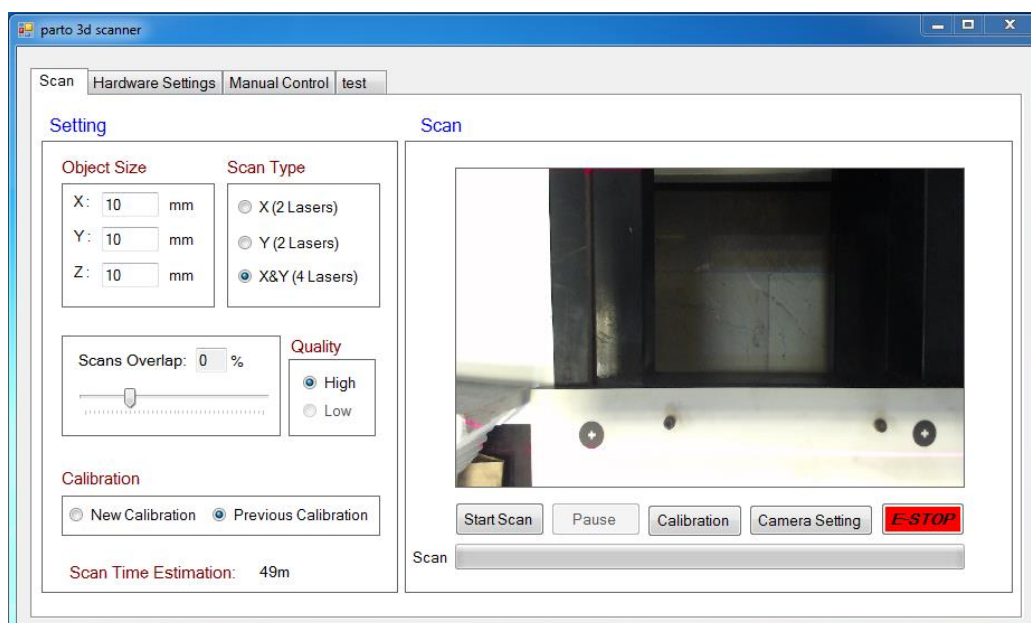


Fig 3. GUI of the P015 Parto Technology laser scanner



2.3. Coordinates calculation concept (Triangulation)

There are different types of active systems that are able to obtain 3D shape of the object by projecting some kind of light on it. One of the simplest, and most accurate types of these systems are those which are based on geometric triangulation. These techniques require a known baseline, and two known angles, camera-object angle and projector-object angle, to establish the triangle and using sine law compute the 3D coordinates of points on the object [7].

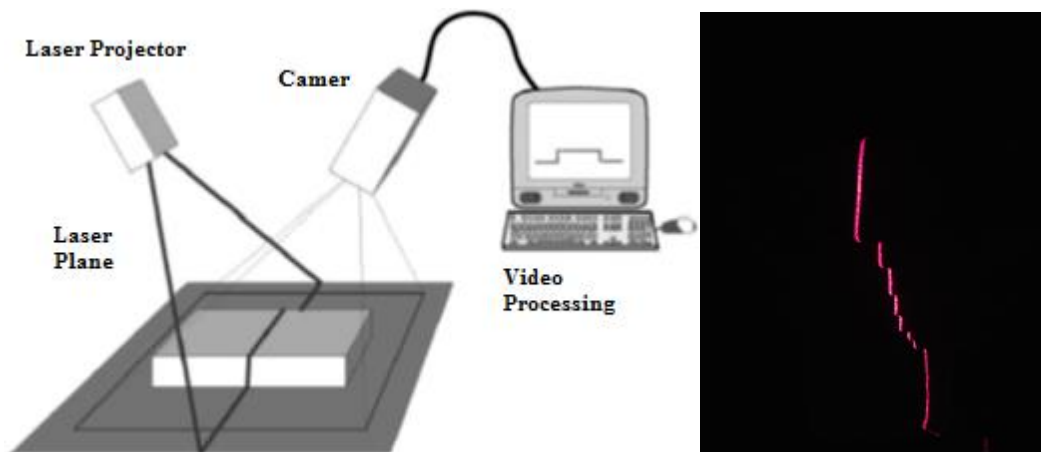


Fig 4. Left) illustration of triangulation laser scanning, [1], Right) laser plane geometry when projected on the object's surface

These systems differ to each other based on the light structure that they use; a single point, linear laser beam, or structured light [1]. P015 is a laser scanner that uses linear laser beams, and using the deformations of the laser line can reconstruct the 3D shape of the object.

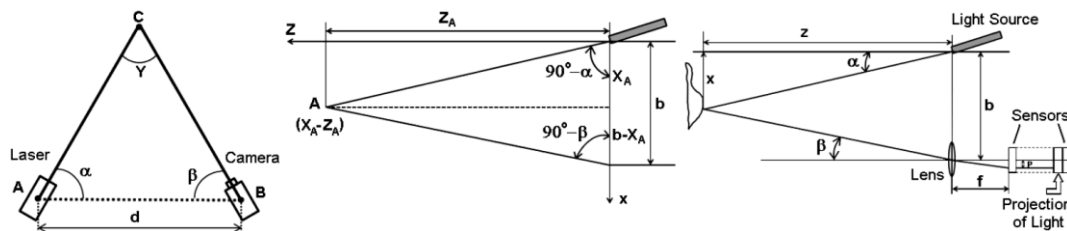


Fig 5. Principle of triangulation-based laser scanning. $Z_A = b / (\tan \alpha + \tan \beta)$, $X_A = Z_A \cdot \tan \alpha$, $\tan \beta = p/f$.

The 3D coordinates of a point from real space, which is projected into the image space can be calculated by the following equations [8]:

$$x = \left(\frac{bx'}{f \cot \theta} \right) - x'$$

$$y = \left(\frac{by'}{f \cot \theta} \right) - x'$$

$$z = \left(\frac{bf}{f \cot \theta} \right) - x'$$

Where b is the baseline length, θ is the laser beam angle, and f is the focal length.

3. Experiments and Results



The experiments section mainly focuses on the steps that are followed to complete a scanning project with P015 laser scanner. For each scanning project 3 main steps should be performed to obtain a reliable 3D model. Object preparation, data collection, and post-processing step that are discussed in detail.

3.1. Object preparation

Each object that is going to be scanned has particular properties that requires customized preparations performed before the scan beginning. Usually industrial pieces are somehow shiny and this causes the laser beams to be reflected from the surface and decreases the accuracy of point cloud generation. In contrast, wooden pieces or some of cultural heritages have opaque surfaces that result in better laser geometry without any reflection of laser beams. The object that is scanned here is a small model of the great Cyrus temple, for which the true data is also available from close range photogrammetry. To produce the true data, 35 convergent images were taken from the object at uniform angles using a 5MP camera, and the model was created using AGIsoft.

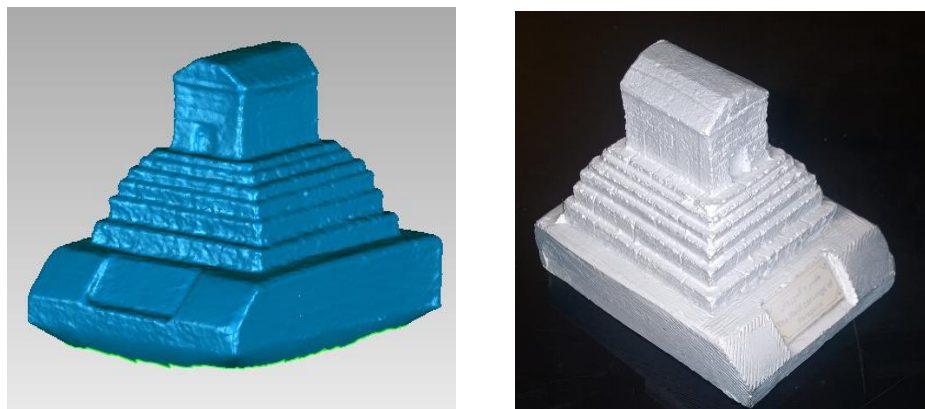


Fig 6. Left) Object (great Cyrus temple), and Right) the true data obtained through close range photogrammetry

The surface of the object is almost opaque, but in order to obtain better scan results, a developer powder was used to decrease the shininess of the object's surface. It should be noted that the thickness of the sprayed powder layer on the object won't become greater than a few microns, otherwise the accuracy of the scan will be affected and the results will become wrong.

Another preparation that should be performed before scanning is the laser scanner calibration process. But because calibration process was performed by company technicians, no information about the operation and parameters is available yet.

3.2. Data collection and point cloud generation

Starting the scanning procedure when the scanner is located in home position, requires the object to be placed besides the right side of the calibration board. Due to the initial motion of the scanner to approximately $X=100\text{mm}$, $Y=100\text{mm}$, and $Z=-100\text{mm}$, when the object is placed besides the calibration board, all parts of the object will be scanned correctly corresponding to the approximate object size that is inserted in the "scan" menu. In fact, scanner movements are calculated and performed based on the object size and height of the scanner's head (height of the scanner's head determines the distance between laser planes).

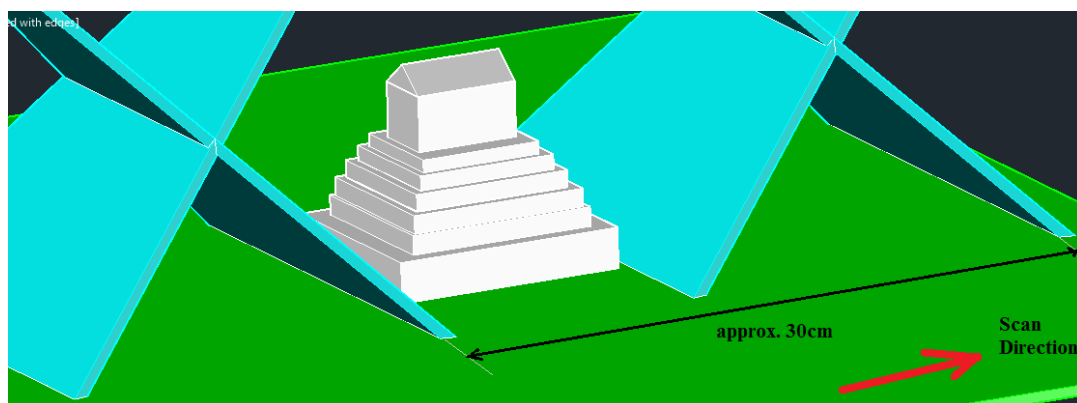


Fig 7. Schematic view illustrating the laser motion length calculated based on Object size and laser beams separation. Cyan demonstrates laser beams, Green shows the board, and the temple at center.

The scan size of the object in the scan direction plus the distance between both laser lines is equal to the movement that scanner moves in that direction. This property makes both laser planes to cover entire object in each scan direction.

For larger objects that will be scanned in more than one scan operation, the overlap between different generated point clouds is a matter of concern in order to be able to register them afterwards. Here, the target object is not so big, but due to 90° angles of walls, that are not visible in one scan, we have to scan it in three orientations such that “top”, “right-side”, and “left-side” of the object are scanned separately and then registered and merged together.

3.3. Post-acquisition processing

After the scanning operation is completed, for each laser beam scanning the object, several ASCII files are created which contain 3D coordinates of the object. For example if the scanning operation was performed in 2 horizontal and one vertical paths, then 6 ASCII files (one for each laser beam) are generated containing point clouds information. These point cloud files are imported in one of commercial point cloud processing software (such as GOM inspect, Geomagic Studio, Cloud Compare, etc.) and other steps are performed in order. Here, various software are utilized to perform different processes.

3.3.1. Manual noise removal

Each scan operation will probably contain some blunders that should be filtered at first. Usually there are a few number of points in the point cloud that have large amounts of error and are considered as blunders; filtering algorithms hardly detect and eliminate these points; so this step is usually performed manually.

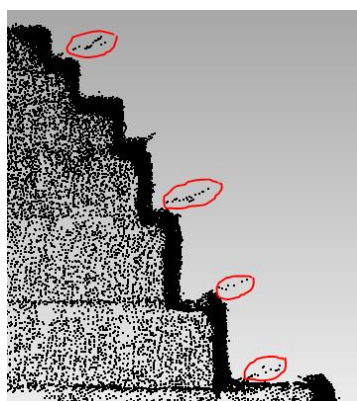


Figure 8. Blunders happening on the point cloud due to reflection (multipass)



Another operation that has been done in order to enhance the final result is to delete those parts of the object that are not scanned properly due to the viewing angles of laser beams. These parts insert a lot of error to the job.

3.3.2. Point cloud registration

One of the shortcomings of the Parto Tech. laser scanner P015 is that individual scans obtained from each laser beam don't register to each other completely and a few millimeters, up to 5mm, is possible for the point clouds to deviate from each other. There are mainly two reasons for this; first, the calibration process performed by technicians was not completed as accurate as possible. Second, laser beam divergence on the object's surface is usually more than a millimeter and this introduces errors to the geometry calculation process.

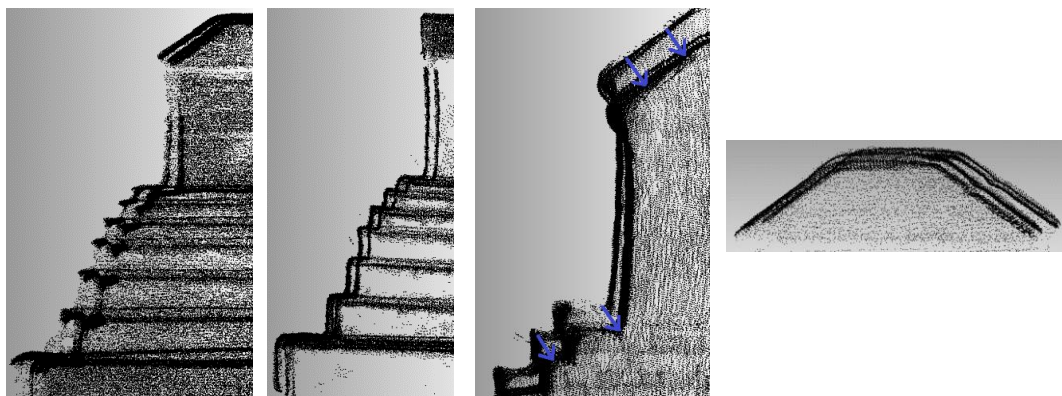


Fig 8. In-scan registration failure

Our purpose in this section is to get a set of point clouds that are registered to each other and are reliable to use in following parts. Geomagic Studio is a software for handling large amounts of point clouds. The software is able to move and rotate the clouds such that they are best fit to each other. This process is performed by the ICP (Iterative Closest Point) algorithm.

After de-noising the point cloud performed in the previous step, we get three sets of data (scans of right, left, and top side) that are neither registered in themselves, nor registered with each other. An approximate manual registration process was performed between these three sets of point clouds. Next step was to globally register all the points together such that a smooth cloud is obtained.

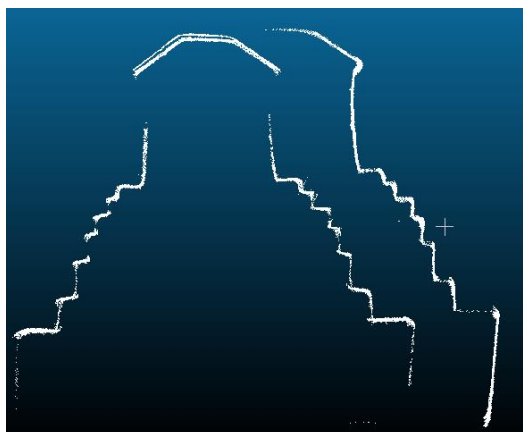


Fig 9. Registration between different scans; top scan with right scan registration, front view of a section



This section was the most time consuming part. After registering data, we found out that individual scans deviate from each other such that the ICP isn't able to match them correctly. Although this deviation is not as large as before and is highly reduced, there exists some skewness on the point cloud surfaces that makes the surfaces rough. We handled this problem by reducing the overlaps of points.

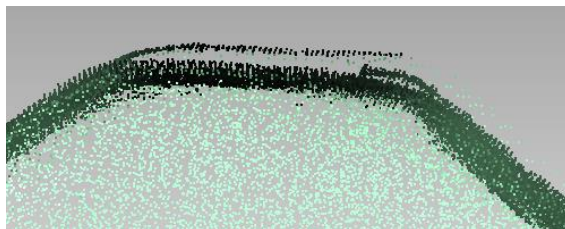


Fig 10. Remaining registration errors after using ICP

In order to do this, each part of the object was borrowed from the most accurate scan, and other scans were omitted. In situations where the overlap of several scans was appropriate and they fit well, only erroneous scans were deleted. The result was a more smooth point cloud with one layer walls and less noise.

3.3.3. Mesh creation

The last step is to triangulate point cloud and reconstruct 3D model of the object. Geomagic was used to create the mesh.

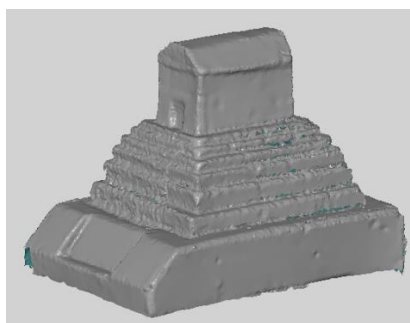


Fig 11. Final produced mesh from laser scanning with P015

4. Accuracy Assessment

As stated before, the reference data are obtained through close range photogrammetry which is possible to produce high accurate models. The analysis performed based on both triangulated 3D models and the error map was obtained from 3D deviations of our model with respect to the reference model. Deviations are color coded and described as a spectrum. Estimated RMS error of the object is 0.72 mm which is about 700 microns. This is 7 times less accurate than the nominal accuracy reported by the company.

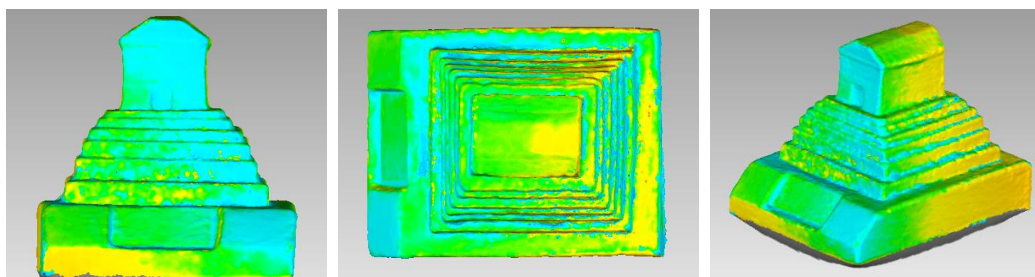


Fig 12. 3D deviations of the model with respect to the reference model

3D comparison results are reported in Table 1. Maximum errors are due to local noise and cannot be a base for decision making, but the average errors are good indices to understand the accuracy of the scanning system.

Table 1. 3D deviation results

| | |
|---------------------------|----------------------|
| Max deviation | Positive: 6.168 mm |
| | Negative: - 6.293 mm |
| Average deviation | 0.166 mm |
| Standard deviation | 0.709 mm |
| RMS estimate | 0.728 mm |

Different reasons may cause the final accuracy results. Divergence of laser beams at different heights, camera settings such as exposure and focus, calibration of the system, and geometry calculation equations and algorithms used to obtain 3D coordinates can affect the final result.

5. Conclusion

Parto Technology P015 laser scanner is an Iranian laser scanner which has the capability to become a very precise scanner. The structure of the device is really stable and movements are properly controlled. Laser divergence angle is very high in this instrument such that in a 40cm length, laser beams thickness becomes more than 5mm, and this could highly decrease the accuracy of the scanning. Because of registration algorithms malfunction, and un-appropriate calibration the point clouds cannot register to each other as well as possible, and this is the reason for low accuracies obtained in this study. Increase in scan speed is highly recommended. Right now, scanning a 10cm cube takes about 2 to 3 hours to complete and this is really not good for real scanning projects. Texture is an important parameter in many projects such as archaeological documentation and P015 is unable to obtain these information from the object. The most recommended change that is proposed to be applied is to add photogrammetric technologies to P015 and enable the device to obtain texture information. Also registration algorithms can be enhanced to obtain better raw point clouds and decrease the processing time after importing to the software.

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