THEALASERMETRY VS MONO LASER SYSTEMS: COMPARATIVE RESULTS ON SIMPLE CURVED PLAINS

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ABSTRACT:

Digital technology for measuring and recording three-dimensional shapes of low morphological complexity (primarily planes), as in the case of architectural buildings, offers a lasting and virtually faithful record that can be used by future researchers. This paper compares the results between two systems. An integrated hybrid system that maximises the data collection capacity of three systems; the laser scanner, photogrammetry and the theodolite (= *thealasermetry*) and a second system which develops a methodology that attempts to fulfil a number of the functions of *thealasermetry* **with less human resources and with less equipment**. Co ordination on site and during the post processing period for *thealasermetry* is indispensable while the mono laser system in study can be used by **one individual**. The Malta Centre for Restoration has applied both techniques in a survey of a barrel vault after a previous case study. The mono laser system resulted in a **more cost-effective and less time consuming** project. The system also overcomes **the metric error propagation** and improves **resolution of texture mapping** compared to the traditional use of laser scanning.

1. INTRODUCTION

The concept underlying this paper was developed as part of the research work underlying the establishment and development of the 3D and 2D Imaging department of the Documentation Division (DD) of the Malta Centre for Restoration (MCR) in the first half of 2003. The issue arose **when determining the extent of time on site and post processing** required in obtaining an ortho photo and 3D model, with digital photogrammetry and *Thealasermetry*.
In a previous paper by the author *Thealasermetry* it was demonstrated how by drawing on the strengths of three systems, more accurate measurements and details can be recorded. The total station co-ordinates are used as the binding factor for the consolidation of all the data gathered from the three systems. Very accurate outline drawings can be obtained with the stereo pairs. Using this system, the laser scan viewpoints can be consolidated within this closed-network. The results are merged into one system. This allows the meshing of the three systems to be modelled together. The same photographs can be utilized for texture mapping the integrated data. Having the photographs directly linked to the total station, ensures that this process is done to the maximum accuracy and ease possible.

The *mono laser system* has come about through the experiences with the 2D and 3D imaging system and the problems of economics and management on site and during post processing. This paper analyses the process of scanning with a long range laser scanner, in a particular methodology to avoid metric propagation error, easy consolidation and easy texture mapping with acceptable resolution **in a much reduced time frame**. This methodology can be established by one person alone, both during the data collection and post processing phase. The results shall be addressed, also in respect of the requirements of each survey.

The *mono laser system* test was organised in the following stages:
A: **A pilot study of the mono system laser scan survey of St Elmo curtain wall** (January 2003) was carried out on parts of a curtain wall. Different scanning viewpoints were selected and photographs at different zooms were taken.
i: using the scanner on a surface of relatively low morphological detail
ii: use the low resolution video camera to take snap shots at the highest zoom level (in this case 5.5 times).
iii: applying these photographs for texture mapping in an automatic manner (eliminating the necessity of using a total station and very sophisticated and expensive metric camera).
iv: achieving a result in a very short period in relation to traditional ortho photo post processing
v: testing the possibility of placing the scanner at different angles and positions to eliminate trees and other derogatory objects in the ortho photo.

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B. **A survey of the Verdala Palace Hall** was undertaken to develop further the data acquisition capabilities of MCR's GS100 scanner and the mosaicing and restitution (including stitching) abilities of 3Dipsos software after the St. Elmo case study. *Thealasermetry* was also applied to compare the two systems.

2. THE DEVELOPMENT OF THE MONO LASER SYSTEM: MAXIMISING THE USE OF THE LASER BY USING A PARTICULAR METHODOLOGY: ST ELMO CURTAIN WALL PILOT PROJECT

As a primary pilot study, a sample survey of a slightly sloping curtain wall in Valletta was selected. This project in fact provided the data both for laser scanning (information on plain surfaces) and the resolution and accuracy of the integrated digital video camera. The data of the scan and photographs was successfully integrated in March 2003.

2.1 On site work

The scan took around 33 minutes, since the mesh did not need a very tight grid. It took around another 50 minutes to take all the photos at zoom 5.5 of the whole façade plus some shots of the higher part at zoom 1 since these were out of sight at zoom 5.5. The second scan took around half an hour to scan and 219 photographic images were shot. The GS100 can be set up and dismantled by one person. The changing light conditions alter the result of the photos. The ideal light conditions would be an overcast day.
Problems with texture mapping were encountered. The integrated camera of the scanner has a relatively low resolution since its primary function at design stage was merely that of an aiming device as opposed to a recording mechanism. For automatic texture mapping at post-processing stage, the digital photos must be taken with the integrated video camera from exactly the same position.

A step-by-step process for the mono laser system approach: In the mono system the most crucial step is the methodology applied in the use of the laser scanner and the integrated camera. The second step deals with meshing the data. The original idea was to use photos that showed most of the wall surface or gave better detailing of features. The photos could be selectively chosen to capture more of the surface. This was unsuccessful for 2 reasons:
A) PHOTOS TAKEN FROM THE LEFT WOULD NOT 'CONTINUE' INTO A PHOTO SHOT FROM THE RIGHT, SO THE TEXTURE MAPPING WOULD GIVE THE RESULT OF HALF A TREE, FOR EXAMPLE.
B) THE PHOTOS FAILED TO 'MEET' EVEN WHERE THERE WERE NO TREES.

It was decided to use the photos taken only from the left scan. These were texture mapped automatically. The photos of the lower wall were taken at zoom 5.5. The upper windows were taken at zooms 2 and 1.5. P**arallax** was especially evident for the balcony and high windows.

2.1 Aberrations in the Mesh

Figure 1: Scan lines appear between one line of photos and another as is evident in this figure and in **Figure 2** (next page).

Figure 2

Scan lines were removed by the following method:

i) Make a copy of the mesh
ii) Texture map a photo taken at zoom 2.5 or less. The lines are not apparent on these photos since the lines that appear are the edge of photos at a constant zoom of 5.5.
iii) The new mesh is at a lower resolution, so the only useful data is that which will cover the black scan lines. Therefore these are cut out from the second mesh as in **Figure 3**.
iv) These lines can then be brought up with the mesh of the main wall to cover the black lines (see **Figure 4**)

Figure 3

Vertical lines appear between one photo and the next photo in the sequence (eg. 173 and 174) as shown in **Figure 3**.
These lines are not apparent when one goes into **Mesh** mode on the scroll bar as shown in **Figure 4.**

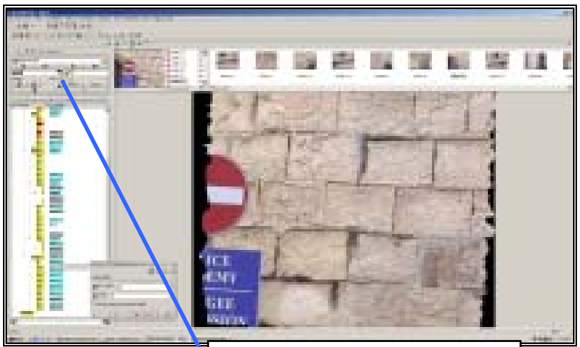

Figure 4

All the photos for the texture mapping where taken from the left scan bar one, where the photo had not come out properly. One photo had to be used from the right scan since a photo from the left scan appeared blank. This was texture mapped manually using the 5 point system.
To date we have been unable to down load this mesh into the list of meshes without these lines becoming apparent again. Therefore the ortho photo was taken while in Mesh mode.

Ortho Photo: The objective of the exercise had been to attain an ortho photo using only the GS 100 scanner and laser post-processing software. This would be achieved by rotating the texture-mapped 3-D model (surface) until gaining a frontal view of the wall. This would eliminate perspective from the view, permitting measurements to be taken. The results attained from the GS100 scan posed limitations to achieving this objective:

Attaining a frontal view of the wall was difficult when the photos did not texture map exactly into place on the mesh because of the **parallax**. The meshed surface become much heavier after it was texture mapped, so a frontal view was first attained with the texture mapping switched off. Measurements where then taken as shown in **Figure 5**. A digital photo was to be taken of the texture mapped surface on the 3Dipsos software.

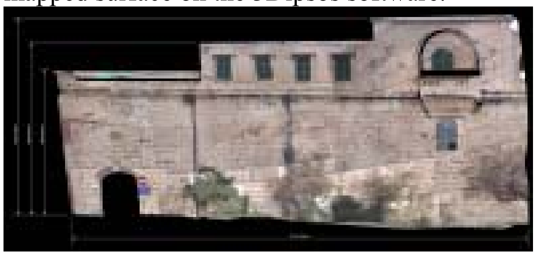

Figure 5

The software offers 2 possibilities for taking photos: Print screen and graphic snapshot. This give a .bmp file. Both photos offer a very low resolution. To resolve this issue, smaller individual photos were taken, imported in Photoshop to be stitched back together. The end photo size was 40cm x 80cm. See figure 5.

Additional Comments: Spheres were not used to consolidate the data. With just two scans of a relatively flat surface it is more straightforward to consolidate worlds interactively rather than automatically using spheres.
Only a scan from one viewpoint is necessary in order to develop a viewpoints angles of **p**

The blue lines between adjacent photos disappear in this mode.

3. THE DEVELOPMENT OF THE MONO LASER SYSTEM: MAXIMISING THE USE OF THE LASER BY USING A PARTICULAR METHODOLOGY: THE VERDAL PALACE PROJECT

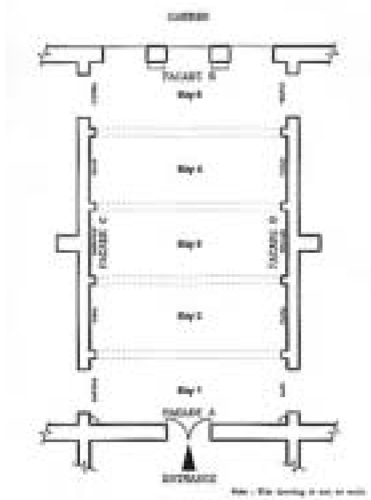

Image 6: Plan of main hall, Verdala Palace (drawing not to scale)

After the experience of the pilot project, a number of modifications were required to improve on the Verdala project. For this project, the documentation project involved the use of a laser scanner, stereo photography (to be used with photogrammetry and texture mapping) and a total station. In this way, the mono system could be compared with *thealasermetry*.

3.1 Reconnaissance

A reconnaissance study was established to study the dimensions of the main hall and draw a plan of the area to document **(Image 6).** This was also necessary to co-ordinate the scanning, photography and total station sessions, so as to ensure that none of the teams are hindered from progressing with their work.

3.2 Dividing the hall in various bays

The hall's barrel vault has ribs which divide the space into 5 bays. It was therefore convenient to follow this structural division and dedicate a scan to every bay **(Image 6).** The GS was placed in the centre of each bay so as to ensure equidistance between the scanner and the façades. This ensured uniformity in the grid chosen and reduced the parallex error encountered in the pilot study. In order to create perpendicular planes between the scanner and the wall surface, the scanner was placed horizontally. Since the scanner was not manufactured to be placed horizontally an iron angle support was devised to place the scanner in the required position **(Figure 7).**
In order to document the façades the scanner was placed in the furthest bay. This position guarantees a larger capture of the entire façade. This ensures that many spheres are included in this scan. The last façade scan was mainly aimed at capturing all the spheres used for registration. Each sphere was individually scanned and then removed so as to photograph the area behind every sphere. This would ensure photographs of the entire hall, including the areas that were being masked by the spheres. In this case, the GS was placed vertically.

Since the project involved the use of the total station, 'prism spheres' were required to obtain absolute co-ordinates. Only three 'prism spheres' were available. These spheres were spread-out in a 3-dimensional triangular position in order to create a solid and stable total station traverse.
A total of 21 white common spheres were strategically positioned to reduce any 'movement' between the various scans during the consolidation post processing session.

Grid: Since the walls are relatively flat surfaces, the team chose to use a grid of c. 8mm

Photographs taken with the scanner's in-built digital camera: Apart from the photographs taken with the Nikon D1, it was decided to use the GS in-built digital video camera to give the possibility of testing the **camera's resolution** at different zoom rates, test if the **parallax** error is evident and the **time consumed** in taking the photographs. It was envisaged to test the pasting of the **photographs automatically** onto the triangulated surface of the scanned data, with a good resolution, thus doing away with having to insert the photographs one by one by means of registering the data of five total station coordinates for every photograph used for texture mapping.

Selecting Camera to use: Since the photographs are to be used for texture mapping they should preferably be in a digital format. It was therefore decided to use the Nikon D1. In order to capture the largest area possible, it was decided that the best lens to be used was the 24mm.
Positioning and naming targets: Each stereopair requires a minimum of 60% overlap. This means that a minimum of 4 targets would be required in each overlap. The targets were numbered for registration purposes.
Lighting conditions: Tungsten lights were used for local light.

3.3 On-site work

Setting up the Laser Scanner: Following the plans drawn up during the reconnaissance, the bays were scanned with the laser scanner in a horizontal position. The scanner's tripod was fitted into a wheeled tripod so as to ease mobility between one scan and the next. An unaccounted problem was the lack of equilibrium resulting from the scanner's body eccentricity being shifted more towards one side. A large stone block was placed on the wheeled tripod so as to counter balance the scanner's weight.

Figure 7: GS Scanner in bay 5, placed in a horizontal position

Individual Laser Scans: In most cases the sphere framing was done via the 'video framing' mode. It was only in rare cases when the spheres happened to be close to the limits of the framing area[2] that the team had to revert to the 'laser framing' mode. The grid selected was

[2] The GS100 scanner has the angle limitations of 60 degrees.

a very tight grid of c. 2mm that works when the scanner is set at Laser scanner Class III. During ‘video framing’ a parallax error was noted; the scanned area was actually shifted to the right of the selected frame. The operators took this error into consideration and selected a larger frame than necessary, thus ensuring all the sphere is captured in the scan.
For each scan, the framing mode selected was the ‘video framing’. When scanning the Bays, each scan captured a larger area than expected, thus gathering some data from the neighbouring Bays. This worked to the team’s advantage as it helped to over come most of the masking effect that would present itself as a result of the shallow ribs dividing each Bay.
Not taking into account the delays resulting from the technical problems, each bay scan took on average 150 minutes to be completed while the Façade scans took approximately 180 minutes. The scans took four days and nights[3] to be completed.

Scanner Photographs: Once each individual scan was complete, photographs were taken with the laser scanner’s in-built digital camera. The operator selected the maximum zoom of circa x 5.5, allowing some overlap between one photo and the next. This proved to be time consuming; each photo session took approximately 120 minutes to be completed. An average of 300 photographs were needed in order to complete one scanned bay area. One of the problems encountered was the various lighting conditions.

Positioning and naming targets: Taking into consideration the area to be photographed, a large amount of targets would have been required. A mobile scaffolding was necessary to stick the targets onto the higher levels. Due to the arch-shaped ceiling, the scaffolding would have to be dismantled section by section every time control markers had to be applied onto a shallower area. Every target was numbered.
Positioning the camera: Since the photographs required were to be equidistant, shots of the ceiling were taken with the camera placed in a central position, catering for both left and right sides of the room.

3.4 Post-processing

There are various methods by which the different GS scanned data could be consolidated: Automatically sphere registration or manually by matching spheres or manually by matching entities. This system has two great disadvantages:
Due to the lack of surveying markers, the operator is restricted in being able to use only the photographs obtained by means of the scanner in-built camera.
The photographer cannot go back on-site to take another session of photographs.

Figure 8. Result of bay 5

Resolution analysis: The resolution of the photographs taken with the D1 Nikon camera was at 300dpi. The photographs taken with the integrated video camera of the GS100 was taken at 72dpi. However since the photographs taken with the D1 were taken at a distance of 4.2 metres the scale of the photographic image (i.e. ratio of real size coverage as compared with the digital back size) resulted in a scale of 1:175. Since a zoom factor of 5.5 was used for shooting the photographs with the integrated video camera, a scale ratio of 1:30 was achieved (a remarkable improvement on the photograph taken at 1 zoom ratio). Another improvement was the ratio of the pixel size of the digital back with the pixel size of the object. With an average pixel size of the Nikon’s digital back of 0.01185mm reflecting a 2.1mm pixel size of the object, the GS100 integrated camera had a ratio of 0.0195mm reflecting a 1mm square pixel size of the object.

4. EXPERIMENTAL RESULTS AND CONCLUSIONS

The results achieved, have proved to be very promising. The site work required for the mono system is very much reduced in comparison with the *thealasermetry* approach. The post processing also proved to be much faster and economical with texture mapping taking nearly a fifth of the normal time required. The resolution achieved with the zoom camera was very encouraging, and proved to be better than the photos taken with the digital Nikon D1 camera.
However a number of improvements are due. The laser scanner’s built-in video digital camera could be of a higher-resolution. Problems with parallax are evident and need improvement. The acquisition software needs to be developed with a more refined algorithm capable of improving on the present parallax error and handling a large number of photos. The post-acquisition restitution software also needs to be developed with a more refined algorithm capable of improving the mosaic form and connection details between one photograph and another.

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