

## **3D HERITAGE DOCUMENTATION**

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**Ahmed Abdelhafiz**

*Civil Engineering Department, Faculty of Engineering, Assiut University,  
Egypt, Email: [a.abdelhafiz@yahoo.com](mailto:a.abdelhafiz@yahoo.com)*

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Nowadays, realistic 3D models are achieved from high resolution texture warped to laser scanner meshes. Multiple photos are normally required for texture mapping, so many manual processes have to be implemented which are absolutely time consuming especially in large sites. The challenge is to handle these processes automatically by developing suitable algorithms. Therefore we focus here on a developed algorithm for automatic texture mapping with its corresponding software. The recent techniques are then used to recover a complete 3D model for paintings inside the Domitilla catacomb which is the largest catacomb in Rome. Such models will help archaeologists to virtually reach the catacomb without putting their feet underground and accordingly conduct their own research.

### **1. INTRODUCTION**

The thorough documentation of heritage sites including their mural paintings is an important step towards researching iconographic content, their allocation within the complex, the chronological development and the explanation of buildings. The referenced three-dimensional models within the architectural space make such important sites accessible without the necessity of going there in person.

The terrestrial laser scanning TLS are one of the standard technologies for object acquisition, as the laser scanner delivers immediately a 3D data set with no further complicated compilation processes. The laser scanning is also an active technology, therefore, there is no problems with daylight or illumination conditions (Jansa et al, 2004). As the laser scanners provide no information about the object's texture, it is reasonable to fuse the color using another sensor which is the high resolution digital camera, (Guaranie, 2004). Digital photogrammetry has also the ability to deliver 3D points together with image information based on automatic matching processes, but with certain precautions and limitations.

This paper aims to show the latest methods and automatic processes achieved for the documentation, which are applied on a large real site "The Domitilla Catacombs in Rome". The 3D model geometry is achieved here by a laser scanner with mounted high resolution digital camera. The resulted images are not that good to be used in texturing. Therefore, a common digital camera mounted on a QTVR head is used under best possible light conditions in order to obtain reliable texture.

A large number of photos is captured from free-positions then registered with the 3D model using tie-points. A challenge in mapping these photos on the geometry is the automation which requires an effective occlusion detection algorithm based on the model geometry. The main characteristics of the used algorithm here are the ability to detect effectively all the occlusion types (ambient, self, and frustum) and to decide the appropriate photo for each face from the 3D mesh full automatically.

The resulted photorealistic model is in the VRML format which can be opened in any standard viewer. The individual paintings will be then used for the creation of a single model of the entire catacomb, which will allow a registration to GIS. Subsequently the data will be available to all archaeologists and architectural historians for further research.

An overview on the site and the expected products is written in section 2. The data collection procedure is then given in section 3, followed by the required post processing in section 4. The automation in texture mapping is presented afterwards in section 5.

## 2. OVERVIEW ON THE DOCUMENTED SITE

The Domitilla catacomb is the largest catacomb in Rom. It is considered to be one of the most complex sites from the architectural structure point of view. It consists of a disordered grid of about 15 km long of underground galleries in up to four levels. Moreover, it saves inside about eighty painted areas of highest interest for archaeologists. These paintings are partially known and not yet accessible to all scientists.

The main goal of the documentation process here is to produce, for further archaeological studies, a high quality documentation of the architecture and the paintings of the catacomb, based on laser scanning technique and digital photography.

The expected products from the documentation are: a 3D model for the whole catacomb structure containing all relevant geometrical information, and accurate photo realistic 3D-models for all mural paintings. A workflow of data acquisition and innovative post processing is developed that allows to handle the entire catacomb in one point cloud. The most important models with wall paintings are also textured full automatically using developed occlusion detection algorithm, which is the main focus of the paper in hand.

## 3. DATA ACQUISITION

The geometry of such complex structure is recovered by a terrestrial laser scanner, while its texture is captured by a high resolution digital camera. For the geo-referencing purpose, 3D points measured by a total station are employed. These points are necessary not only to connect the output with the local coordinate system but also to reduce the number of scan positions and to control the registration of all scans. A number of reflected targets are therefore distributed along the main corridors and staircases. The 3D coordinates of these points are then recovered using Leica TCRM 1103i total station.

The scans are achieved by a terrestrial laser scanner Riegl LMS Z420i mounted by a digital camera. It permits a measurement range between 1 and 800 metres, measurement accuracy of 8 mm standard deviation, and measurement rate up to 12000 points per second. The scanner field of view is 80° x 360°, more information about scanner specifications can be found in Riegl homepage ([www.riegl.com](http://www.riegl.com)).

In the course of eight measuring campaigns, nearly 2000 positions have been scanned resulting in about two million points for each scan position. The scans are registered together in the total station points coordinate system using the reflected

targets which can be detected automatically in the point cloud. Some of three thousands of reflecting targets are used as tie-points.

The camera mounted on the scanner delivers poor textures that can't be used for high quality texture for the important mural paintings. That is why a Canon EOS 1Ds digital camera with a 14 mm objective is used to capture free hand photos from the best available positions. A professional lighting system with a flexible light panels made by KINO FLO is also used to overcome the problem of the underground light conditions.

#### 4. POST PROCESSING

Manual, semi automatic and automatic methods for point cloud registration are presented in details in references like [Zhang, 1994; Ripperda and Brenner, 2005; and Wendt, 2008]. In our case, the overlapping is crucial as good registration requires large overlap. But at the same time the large overlap requires larger number of scan positions. In case of small overlap, large errors are expected which has to be controlled using total station measurements.

With the small overlap between the scans in the Domitilla, a large error between the point clouds registration is obtained. Therefore measured total station tie-points are considered, figure 1 shows the final registered point cloud after using the total station tie-points.

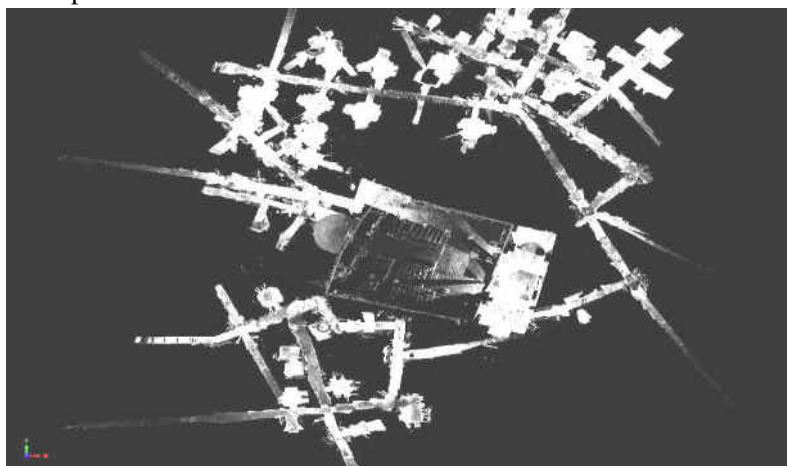


Figure 1: The final registered point cloud of Domitilla site using total station tie-points

Digital images are registered here using photogrammetric software (3DM CalibCam) by Adam Technology. For a short post processing time in image matching, it is important to consider sufficient overlapping of the employed images and optimum ratio between the base line and the distance to the object, see figure 2 for an example of a set of photos captured for a cubiculum. The existence of at least three tie-points measured by a total station allows registering the photogrammetric model on the local coordinate system and in the right scale. Self calibration for the used camera is also achieved during the photogrammetric solution as enough number of photos and control points are available. The point cloud resulted from the laser scanning or from the photogrammetric solution can be then meshed in a 3D model as shown at the right of figure 2.

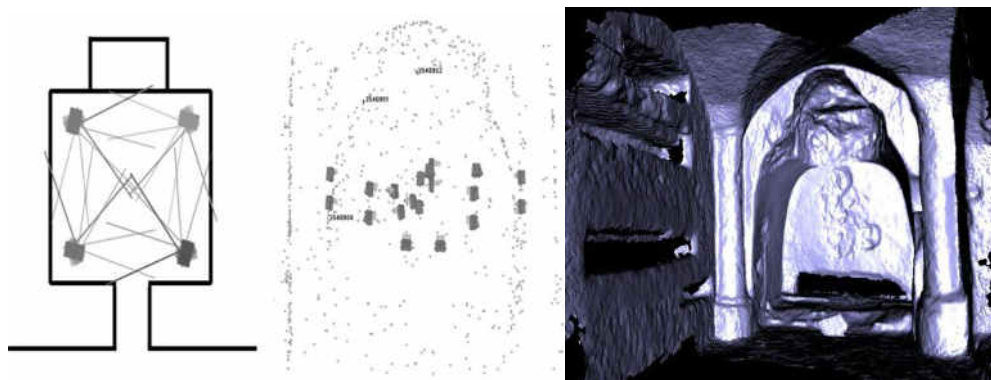


Figure 2: Scheme for camera positions in a painted room; calculated camera positions by 3DM CalibCam; mesh model.

## 5. TEXTURE MAPPING

Texture mapping procedure needs several manual processes which require long time. Several days and sometimes several weeks for more complex objects are needed to achieve good results. This is with no doubt time consuming and consequently cost consuming. Therefore the automation presents a challenge in executing this process. The texture mapping process can be divided into three main steps which are; projecting triangles on photos, occlusion detection, and appropriate texture assigning.

Where collinearity equations are commonly used to project triangles on the oriented photos and the appropriate texture is assigned through a certain comparison process between the available textures, the real obstacle to employ the automation in texture mapping is the occlusion detection step.

Occlusion detection algorithms like the z-buffer algorithm [Catmull 1974] and the painter algorithm already exist. While the z-buffer algorithm requires large RAM, the painter algorithm [Goodrich, 1992] is computationally expensive. [Grammatikopoulos et al., 2004] has speeded up the searching process of the z-buffer algorithm by tessellating the textured image area into a rectangular grid with cells larger than those of the original image in order to create digital ortho-photos.

[Alshwabkeh and Halla, 2005] has detected the occlusions by employing an object space threshold and an image space threshold. Although using such thresholds detects simply the visibility status, the algorithm shows low sensitivity as selecting small thresholds values may wrongly classify visible parts as occluded and selecting large thresholds values may classify occluded parts as visible. [Abdelhafiz 2009] has also detected the occlusions effectively by classifying mesh vertexes into visible and non-visible layers without any misclassification.

Employing multiple photos commonly results in multiple textures for the same triangle. The image with the best texture quality is then selected and employed. Another approach to deal with the available multiple textures is to blend all textures together [Grammatikopoulos et al., 2004; Visnovcova et al., 2001]. The textures of the images are blended according to the weight which is proportional to the area of the projected triangle on each image. Blurring in the textured model is experienced as a result of the blending process.

In this work, the Multi Layer 3DImage algorithm [Abdelhafiz 2009] is in principle employed. The required modification to fulfil this project needs is then made. The modified algorithm is integrated in the 3DImage software. All these points together with some results of real paintings from the Domittila catacomb are presented in the following subsections.

## **5.1 The original ML3DImage algorithm**

The main function of the original ML3DImage algorithm [Abdelhafiz, 2009] is to employ multiple photos captured from different points of view in order to texture a given mesh automatically. Registering photos with the mesh model is a step before starting the algorithm. The objects geometry is then investigated in order to assign all the occluded parts on each photo.

Considering a number of photos (N) registered in the same coordinate system of the object model, two main tasks are executed in order to texture the model employing N photos which are; detecting occluded parts in the mesh and assigning the appropriate photo for each triangle of the mesh. Details of these two tasks are given in the following sub sections.

### **5.1.1 Occlusion detection**

The following three steps are executed for each photo of the available images:

#### **1) Constructing 3DImage for the concerning photo ( $P_i$ )**

Having the camera interior orientations parameters (from a calibration process) and the photo exterior orientations, the mesh can be projected on the concerning photo using collinearity equations. Each triangle vertex is then attached to its corresponding image pixel; see [Abdelhafiz et al, 2005] for more details of the construction of the 3DImage. All the attached vertexes are labeled as visible by default then classified into visible and non visible in the following step.

#### **2) Classifying mesh vertexes into visible and non visible**

The vertexes visibility is assigned by a visibility indicator (1/0) according to the vertex visibility status. In this step, occluded vertexes are sent to one of the back layers and labeled as non visible (0). Two types of points are considered. Points like (A) and points like (B) as shown in figure 3. Vertexes like (A) are occluded by other points (A1). This means that these two vertexes are corresponding to one image pixel. According to the fact that the point near to the camera is visible and the far one is invisible, the visibility status for the two points can be defined.

For points like (B) which are occluded by the object surface itself, all light rays connecting the vertexes with the exposure station are checked if they intersect with the object surface or not. If yes, this means that the checked vertex lies behind the object surface i.e. occluded. So this vertex will be sent to the back layer, otherwise it will remain on the visible one.

#### **3) Detecting and labelling occluded parts**

Whereas vertexes on the visible layer are assigned with visibility indicator (1), vertexes on back layers are assigned with visibility indicator (0). The visibility indicators of the

three vertices of any triangle are then used to decide the visibility status for that triangle from the point of view of the concerning photo ( $P_i$ ), see figure 5 left side. If the visibility indicators of the three vertices of the triangle are (1) then the triangle is completely visible (e.g. triangle M from station\_1 or station\_3). If the visibility indicators of the three vertices of the triangle are (0) then the triangle is not visible (e.g. triangle M from station\_2). In case of one or two of the triangle vertices have (0) visibility indicator, so the triangle is partially occluded and the texture from that photo will not be considered (e.g. the edge triangle E from station\_1 or station\_2).

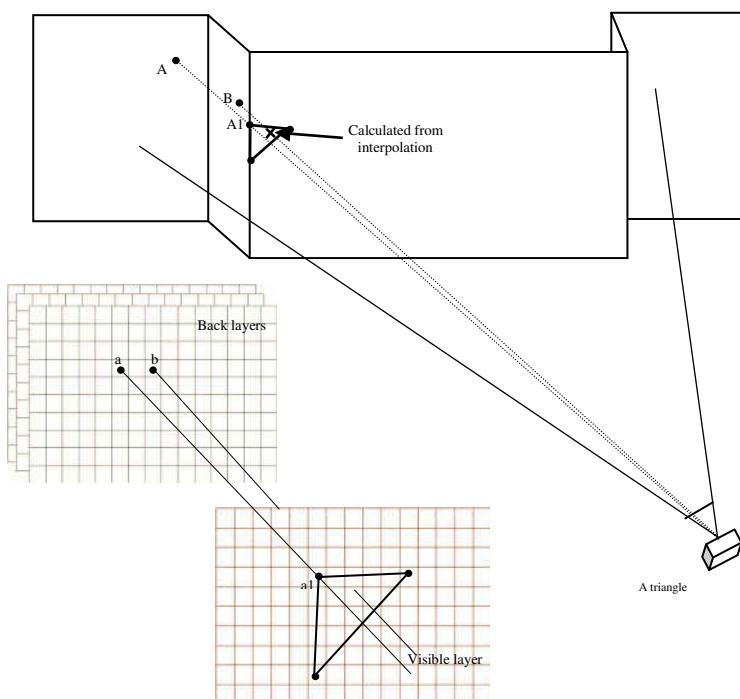


Figure 3: The classification of points into visible and non-visible layers.

### 5.1.2 Assigning the appropriate texture

By repeating the occlusion detection step with all the available photos, occluded parts on each photo are assigned as non visible. For triangles which appear in just one photo, this photo will be directly assigned to texture such triangles. On the other hand, triangles appeared in more than one photo are the concerning triangles in this step, see figure 5 left side. Due to the fact that rich texture is obtained from the photo with the largest triangle projection, this criteria is used in this algorithm as a control condition in case of multiple photos are available for texturing a certain part of the object.

## 5.2 Applying the ML3DImage algorithm on one of the paintings

In this section, one mesh model of a painting with 400,000 triangles is presented. Eleven photos are selected from the available photos for texturing purpose. The original mesh model and the resulted textured model are shown in figure 2 and 4. The variation in the radiometric characteristics between the used images can be easily

noticed in the photo realistic model (red circles). This occurs as the used algorithm searches for the most rich texture between the photos and consequently use more than one photo to texture one wall painting. Therefore, it will be more convenient to texture each one wall painting from one photo. In order to let the algorithm understand and accordingly fulfil our requirements automatically, some modifications for the algorithm are made as will be described in the following section.



Figure 4: A mesh model of one painting from the Domitilla catacomb including artifacts.

### 5.3 Modified ML3DImage algorithm and the corresponding 3DImage software

The algorithm modification aims to push the algorithm to texture a certain part from the mesh model from a certain photo. The idea behind is to mask this part in the remaining photos with a specific colour. Accordingly, the algorithm will detect this colour and consider it as occluded areas. In that case, the only choice for the algorithm is to use the photo without masking to texture this part.

For instance in figure 5 right side, please focus on the left part (L). If the algorithm is applied normally (as in the left side), (L) will be textured from station 3. Here it is required for any reason to push the algorithm to use station 2 in texturing this part. Therefore (L) part is masked with black colour as shown in the figure. Looking for the interpretation of part (L) under the figure, the only available choice for the algorithm is to use station 2 to texture (L) part.

Another useful modification is the ability to give priority to certain photos, for example to texture a complete wall painting from one photo, the painting can be selected in that photo then mask all the remaining part of the photo. With giving the masked photo priority, the modified algorithm will use this photo first to texture all the painting then use the other photos to complete the rest of the model. These two modifications are used to better texture the mesh model under investigation without any artefacts, see figure 6 for a textured model free from the pre-mentioned artefacts.

The modifications are integrated in the 3DImage software which is developed and modified by the author. The software is originally designed to texture laser scanner mesh models full automatically employing the ML3DImage algorithm. The software input is a mesh model together with all the available photos. A data file with the interior and the exterior orientations for all the employed photos is also required. All the required data is then organized in a batch file which can be created using an interactive procedure employing the same software. Afterwards the software starts the processing which ended with a photo realistic model in the VRML format.

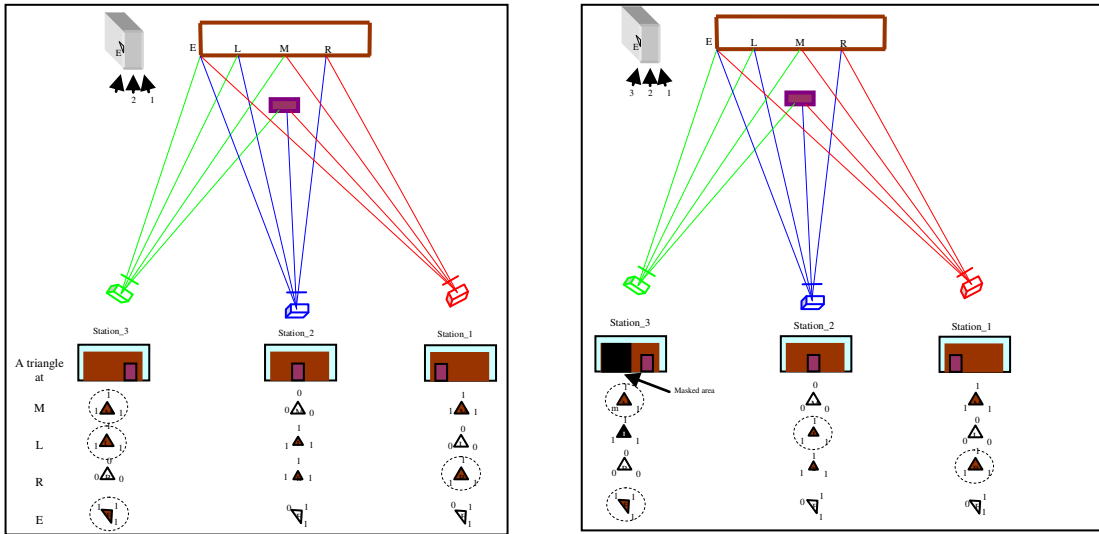


Figure 5: The principle of executing the original ML3DImage algorithm and the execution in case of existence of masked part.



Figure 6: A photo realistic model of one painting from the Domitilla catacomb textured with the modified ML3DImage algorithm.



## 6. CONCLUSIONS

In this paper, a multi layer 3DImage algorithm for occlusion detection is used in an automatic texture mapping approach using multiple photos. As a part of this work the ML3DImage algorithm is further developed and modified then integrated in the 3DImage software which is developed by the author. The modified algorithm with its corresponding 3DImage software shows the reliability and the efficiency to apply the texture mapping process on 3D models full automatically. A successful reconstruction for the Domatilla catacomb in Rom is also presented and a textured 3D model in the VRML format is generated and visualized.

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## التوثيق الحضارى ثلاثى الأبعاد

دكتور مهندس / أحمد عبد الحفيظ أحمد

قسم الهندسة المدنية ، كلية الهندسة ، جامعة أسيوط

Email: [a.abdelhafiz@yahoo.com](mailto:a.abdelhafiz@yahoo.com)

### الملخص العربى:

في الوقت الحاضر يتم عمل النماذج ثلاثية الأبعاد للأهداف الحضرية باستخدام جهاز الماسح الضوئى. يتم بعد ذلك تحويل سحابة النقاط الناتجة الى مجموعة من المتلثات التى تكون أسطح الهدف. بأخذ صور رقمية عالية الدقة يمكن إضافة النسيج الحقيقى لأسطح الهدف. وعادة ما يلزم عدد من الصور لعمل النسيج المطلوب (texture mapping). الأمر الذى يتطلب عمليات يدوية كثيرة والتي تعتبر أهدار للوقت والجهد خصوصا مع الأهداف الكبيرة. ويتمثل التحدي في عملية الـ ( texture mapping) فى تطوير خوارزميات مناسبة للتنفيذ الأوتوماتيكي. ولذلك تم التركيز فى هذا البحث على خوارزمية وضعت لعمل النسيج المطلوب (texture mapping) أوتوماتيكيا. وتم عمل برنامج كمبيوتر لتطبيق هذه الخوارزمية . ولقد تم استخدام التقنيات الحديثة لعمل نموذج ثلاثى الأبعاد لمنطقة الدوماتيلا والتي تعد أكبر مقبرة في روما بإيطاليا . ومثل هذه النماذج سوف تساعد علماء الآثار لدراسة المنطقة وإجراء البحوث الخاصة بهم فى الحقيقة التخيلية (virtual reality) دون أن يضع أحد قدميه هناك.