IMEKO International Conference on
Metrology for Archaeology and Cultural Heritage
Lecce, Italy, October 23-25, 2017

# Multi-wavelengths3D laser scanner for investigation and reconstruction of19$^{th}$ century charcoal inscriptions

Massimiliano Guarneri[1*], Sofia Ceccarelli[2], Massimiliano Ciaffi[1]

[1]*FSN-TECFIS-DIM, ENEA, Frascati (RM), Italy*
*massimiliano.guarneri@enea.it, massimiliano.ciaffi@enea.it*
**Corresponding author*
[2]*ENEA Guest, recipient of GARR scholarship, Rome, Italy – sofia.ceccarelli@enea.it*

***Keywords**: multi-wavelengths laser scanner, 3D colour models, charcoal inscription,image enhancement, morphological operators, text recognition.*

***Abstract*** **– Digital reconstruction is nowadays a widespread practise and, at the same time, a useful tool in CH field, starting from the study of works of art up to the delineation of conservation actions. The present work describes the use of the ENEA 3D laser scanner prototype, called RGB-ITR, for a deepen investigation of 19$^{th}$ century charcoal inscriptions on wall drawings, placed in the Saint Sebastian Door of the monumental Aurelian Walls (Rome), with the aim of understanding the historical value. The results of post-processing analysis of the high detailed 3D models with properly-developed algorithms allowed the preliminary reconstruction of the contents, demonstrating the value of the adopted technique for 3D digitalization of the room thanks to its features, such as independence from variable lighting conditions, acquisitions at great distances and no need of area interdiction or scaffolds.**

## I. INTRODUCTION

The identification and reconstruction of the contents are important aspect for the historical-artistic overview, the understanding and the preservation of the Cultural Heritage. Scientific researchers, art historians, archaeologists, restorers and conservation scientists should always collaborate in order to obtain a deepen knowledge of the investigated work of artsand to facilitate an appropriate conservative plan.

This work presents the on-going multidisciplinary study on high detailed 3D models of the tower room of Saint Sebastian Door belonging to the Walls Museum in Rome. One of the museum experts' requests was to analyse and focus the attention onthe particular charcoal inscriptions, dated back to the 19$^{th}$ century that characterize the room decorations.

The 3D digitalisation of the entire room has been achieved by the ENEA laser scanner prototype, called RGB-ITR. This system has proven to be a convenient solution for this particular case study, permitting to acquire data at 5-11 meters high from the floor without illumination influence, area interdiction or scaffolds usage.

The present and the future studies in this site, in according with the stakeholders' requests, aim to understand not only the inscriptions contents and therefore their historicalvalue, but also to assign achronological framing to both drawings and inscriptions. The preliminary results presented in this work have to be considered as starting point for a deeper and collaborative analysis of the room for twopurposes: on one hand, delineate its role during the centuries, on the other, get a globaland detailed vision of the room for conservation and dissemination.

## II. CHARCOAL INSCRIPTIONS ON DRAWN WALL

The investigated room is located inside the oriental tower of the Saint Sebastian Door, so called for the nearby presence of the homonymous Basilica, and it is part of the monumental Aurelian Walls, in Rome (Fig. 1).

The construction of the defensive walls was commissioned by the Roman Emperor Aureliano in 271 a.C., after barbarian hordes came to Italy threatening important cities, and concluded in 279 a.C., representing one of the best example of military architecture. This monumental structure, which represents an advanced building skill for the historical period, ran about 19 km around Rome, including the hills and every important area of the city, with square towers placed at a distance of 100 roman feet (29,60m). Doors were built in the intersection with consular streets (17 in total), and had one or two arches often between two semi-circular towers. Most of the doors was made of travertine blocks but some of them, such as the San Sebastian one, had marble coating. This Door, originally called Appia Door, had a peculiar dual locking system (a shutter and two double-sided wood swing) and two semi-circular towers[1][2][3].

The room digitalised in this work belong to the occidental tower.Before the 19th century a second floor in correspondence of the decorations and a higher third one were present.Nowadays, the tower room consists of a single open space accessible from the bottom floor. The entire structure is about 11 meters high and the most significant and visible drawingsare placed at about 5 meters high from the floor,made of charcoal on plaster with dark brown and black colourfigures[1].

The history of the room decoration is quite ambiguous because of the uncertain age and authors'drawings and inscriptions assignment. Several hypothesis has been formulated,but the most reliable one, according with historians,ascribes the decoration elements to soldiers belonging to the papal ranks stationed in the Appia Door between 18th and 19th century. The second supposition distinguishes historically the two elements: the drawings, assigned to Battista Franco, would be dated back to the 16th century as preparatory sketches on which the door decorations were based on for the victory of Carlo V over the Turks. The inscriptionsremain attributed to soldiers lived inside the monumental door during the 19th century until Italy unification[4][5]. Surely, more historical and iconographic studies are needed for a better comprehension of the site.

*Fig. 1:Saint Sebastian Door of the Aurelian Walls, Rome.*

## III. IN SITU ACQUISITION METHOD

The RGB-ITR (Red Green Blue – Imaging Topological Radar) systemis a 3D laser scanner able to digitalize surfaces up to 30 meters of distance using three amplitude-modulated(AM) monochromatic wavelengths(660 nm, 517 nm and 440 nm) superimposed in a single laser beam that scans the surface thanks to a system of lenses and mirrors. More information about the system and the technique can be found in [6][7]. One of the main characteristic of the RGB-ITR scanner is to store the structural and colour layers data as ordered matrix, allowing to inspect the raw images not only as a 3D coloured model, but also as photographic frames for a rapid and sometimes more clear interpretation: this feature is also a direct consequence of the implemented scanning setup, which allows to cover uniformly the entire inspected surface following a pattern similar to a TV raster.

To ensure the better digitalisation quality of the painted parts of the wall, the optical setup was preliminary adjusted: because at the moment the RGB-ITR scanner is not equipped with an autofocus system, the launching and receiving lenses focus optimisation has to be performedbefore the digitalisation phase.This procedure can be obtained by acting on two separated micro-steps XYZ translation mounts, which can move the launching and receiving optical fibre respect to the lenses set.The average lasers spot size, responsible of the pixel resolution, and the receiving signals were optimized at a distance of 6m.The digitalisation of the room has been provided moving the system in seven different positions (an example is shown in Fig. 2) in order to have equidistantpositioningof the scanner from the investigated surface.

To ensure a colour uniformity of the collected laser data, several calibration procedures between different instrumentation positioningwere accomplished.

The calibration data were collectedin a range between 3-10 meters from the optical head, illuminating a white certified target,placed on a tripod,by the laser beams and moving it every 50cm.The datasetswere used to balance the distance and angular effects typical of the optical signals acquired by the RGB-ITRscanning system [8].

*Fig. 2: The RGB-ITR system inside the tower room.*

The 3D model of the entire tower room (Fig. 3) has been obtained in about 130 hours, working also during the night and without interdicting the room to the visitors.

*Fig. 3: A screenshot of RGB-ITR laser coloured mesh of the room.This preliminary result is obtained just by applying the calibration dataset to the raw laser scanner data*

In *Tab. 1* the descriptions of some scene and digitalisation parameters are reported.

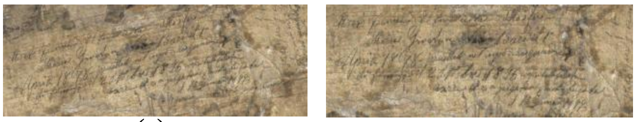
*Tab. 1: Scene and digitalisation parameters*

| | |
|---|---|
| Scanner/drawing distance | 5500 mm |
| Drawing size (WxH) | 1047x1682 mm |
| Drawing resolution | 5300x7700 pixels |
| Drawing spatial resolution | 0.197x0.218 mm/pixels |
| Average letters size | 6.55x6.32 mm |
| Average letters resolution | 32x27 pixels |
| ITR average spot-size | 0.2 mm |

## IV. IMAGE PROCESSING FOR HANDWRITTEN INSCRIPTION ANALYSIS

The 3D model generation, colour calibration and post-processing analysis of the all digitalisationshas been executed by an*ad-hoc* software, called *itrAnalyzer*.Thefeatures of this software are the result of an ongoing development and experimentation, which follow the scanner evolution and specific real case studies requests.As for the development of the ITR scanner, the itrAnalyzer software follows the idea to be a general purpose and a valid support instrumentfor analysis and diagnostic issues, especially in the Cultural Heritage field. Even if a lot of existing software could give a generic and local solution to the specific problem of the inscriptions placed on the tower room walls, the aim of developing and including custom algorithms and proceduresinside the itrAnalyzer tool is to give a ready-to-use instrument for similar case studies, allowing to solve the handwriting recognition issue directly on-site.The final goal of this work follows the interesting results obtained in other fields like demonstrated in [9] for the medical sector.

As in the photographic cameras, the ITR scanner has intrinsic optical deformations, due to the laser paths over the surface, which can be automatically corrected by the point-to-point spatial information.Even if actually the preliminary results presented in this work focus the attention on processing just the coloured information, in the future the spatial information will be used for removing optical distortion and permitting a correct and automatic character recognition.Fig. 4shows the lasers colour matrix crop (a) of the studied handwritten inscription compared with the optically corrected ones (b).



(a) (b)

*Fig. 4: (a) shows the laser colour matrix crop of the inscription acquired by the scanner. (b) shows the same crop corrected of the optical distortions due to the ITR scanning system setup.*

The major effort made for the handwritten inscriptions identification was testing and developing customized algorithms, based mainly on morphological operators, contrast enhancement and background removal. As starting point for these studies, a particular inscription over one of the fourcolumns of the tower room was chosen.

As reported onTab. 1,the average digitalised letters resolution can be quantified in 32x27 pixels.As visible inFig. 4the handwritten inscription presentsan irregular calligraphy in some words and some missing parts. For testingthe identified algorithms, a reference sample was created copying a small part of the inscription wall and overlapping on it a font type present in the library of the computer: the chosen one was the “Apple Chancery” font, just for a closer similarity with the handwritten inscription type. For a more realistic effect with the case study in exam, the font was filled with a 30% grey level colourand thena 50% fade was applied.The result of the letter “e” sample is shown in Fig. 7a.

For both background removal and handwritten letters enhancement, a set of structuring elements and morphological operators were applied. The structuring element used for the morphological operations is a binary image, where the true pixels are used in the morphological computation, discarding the false values[10][11]. In this preliminary phase, a good result was obtained just applying the most common morphological operators: the dilation, which the final effect is to enlarge gradually the outline of the foreground pixels (typically true values); the erosion, whichhas the effect to reduce the contour pixels of the foreground region.To simulate also the charcoal head shape, a combination set of these two morphological operators, called opening and closing, has been chosen.The first was used especially for the background layer creation, while the second to fill the holes left by the subtraction of the background from the original image. An example of how these operators work is shown in Fig. 5 and Fig. 6.

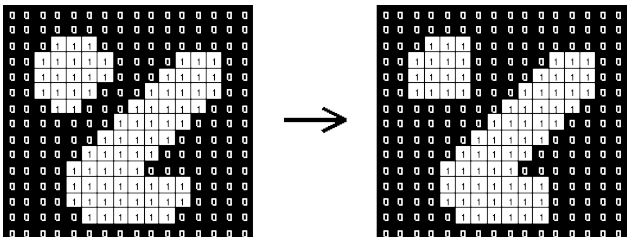


*Fig. 5: Effect of opening using a 3×3 square structuring element*

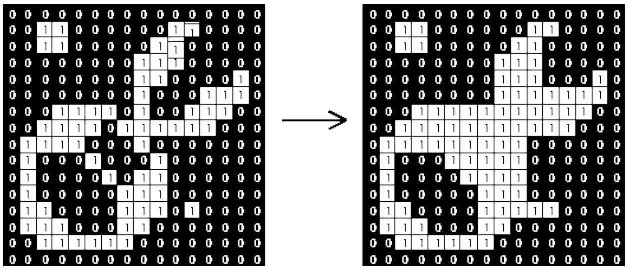


*Fig. 6: Effect of closing using a 3×3 square structuring element*

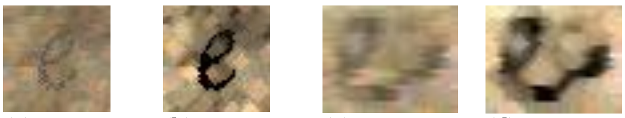
For the background removal,the selected structural elementwas a disk with a ray of 5 pixels, which ensured to preserve lighter letter to be treated as background itself.For filling the holes, a disk with a ray of 2 pixels has been chosen: in this case the choice was forced by keeping the shape of the smallest letters present in the inscription.The most significant effect of the background removal and image enhancement was obtained in this case by converting the RGB (Red Green Blue) laser coloured datainto the HSL (Hue Saturation Lightness) space and applying the morphological operators only to the lightness layer. To be thorough, a pseudocode list of the main operations of the described procedure is reported:

```
01    A = rgbInscriptionCrop;
02    hsl = rgb2hsl(A);
03    l = lightnessInscriptionCrop;
04    se1 = structural_element(circle, ray1=5);
05    se2 = structural_element(circle, ray2=2);
06    bckgrnd = opening(complement(l), se1)/ray1;
07    fg = complement(complement(l)-bckgrnd);
08    enhImg = hsl2rgb(unionOf(h,s,fg));
```

The necessity to make the complement of some matrices, as reported in lines 06 and 07,is due to dark colour of the handwritten inscriptionsto detect. The above described procedure was tested on both reference “e” sample (Fig. 7a-b) and the real case “e” character (Fig. 7c-d).
The identification and test of the right parameters for the above described process is crucial for furtherdevelopments[11][12][13] of an automatic procedure for the identification of the single letters, which compose the impressed phrases.

## V. RESULTS AND CONCLUSIONS

The results of this study demonstrated the validity of this kind of instrumentation in an unusual application, achieving calibrated colour and structural high detailed information of charcoal drawings and inscriptions collected at significant distances without the need of using scaffolds and photographic setup.



(a) (b) (c) (d)

*Fig. 7: (a) the "e" sample created for the algorithm choice and tuning; (b) the “e” sample after the image processing; (c) one of the handwritten “e” found on the wall; (d) the real case “e” after the image processing*

The study of the RGB-ITR images allowed to point out detailsnot visible by the naked eye observation from the ground. Post processing analysis of the 3D model have permitted the extrapolation of the inscription from the background (Fig. 8) and the partial reconstruction of some of the contents of drawings located at 5 meters high.A preliminary interpretation of the inscription is:

*"Mastro Francesco (...) della sposa*
*Maria Giustini Bari il 1° Aprile 1878 arruolato nel corso della guerra e di passaggio il 2 ottobre 1896 visitata questa torre eaggregato a questa brigata il 18 gennaio 1899.(...) Giovanni "*

*Fig. 8: Preliminary post-processed image of one of the charcoalinscriptions.On the top a view where the inscription is placed respect the drawings. In the centre the post-processed area overlapped (transparency at 20%)to the original textured mesh(transparency at 80%)*

The interpreted content of the inscription on the charcoal drawingconfirms the theory of the soldiers stationing inside the San Sebastian tower during the 19th century.

The additional value of this work is not just in the single application of the different methodologies (3D/2D digitalisation, colour compensation, image enhancement, handwrites recognition[12][13] and then 3D model reconstruction), which if realised with conventional techniques and instruments can be procedural and time demanding, but in the simultaneous hardware and software development of a tool able to act directly in-situ for a prompt analysis and diagnosis of different Cultural Heritage set of problems[14]: in fact the generalisation of some of the techniques here described can also be applied forhidden details discovery, defect detection andimage segmentation.

## ACKNOWLEDGEMENTS

A special thanks to the Capitoline Superintendence for Cultural Heritage of Rome, in particular to its referent and Aurelian Walls Museum Director Ersilia Maria Loreti for the logistic and support during the digitalisation campaign.

Thanks to the ENEA researchers Mario Ferri de Collibus, Giorgio Fornetti, Massimo Francucci and Marcello Nuvoli for the development and modernization of the system.

The presented work has been performed within COBRA project (lr13/2008 project n.1031) funded by Latium Region and we thankthe project responsible Roberta Fantoni for the support during the entire campaign.

## REFERENCES

[1] Montesanti A., *Le Mura Aureliane. Storia della cinta difensiva di Roma*, laStoria, Rivista online di Storia e Informazione,nn27-28, 2007;

[2] Brizzi B., *Mura e porte di Roma antica*, Roma 1995;

[3] Pisani Sartorio G., *Le Mura*, Collana Roma Imago Urbis, Istituto Poligrafico e Zecca dello Stato, Roma 1995;

[4] Staccioli R.A., *L'arco di Druso e la porta San Sebastiano* in *Capitolium*, 1969, XLIV;

[5] Tomassetti G., *La campagna romana antica, medioevale e moderna*, ed. a cura di L. Chiumenti e F. Bilancia, Roma 1975, vol. II;

[6] Guarneri M. et al., *Remote colorimetric and structural diagnosis by RGB-ITR colour laser scanner prototype*, Advances in Optical Technologies, Hindawi Publishing Corporation, Volume 2012, Article ID 512902, 6 pages, doi:10.1155/2012/512902;

[7] Guarneri M. et al., *3D remote colorimetry and watershed segmentation techniques for fresco and artwork decay monitoring and preservation*, Journal of Archaeological Science, 2014, vol46, doi: 10.1016/j.jas.2014.02.020;

[8] Ceccarelli S. et al, *Colorimetric study on optical data from 3D laser scanner prototype for Cultural Heritage application*, Springer International Publishing AG2017, *New Activities for Cultural Heritage, Proceedings of International Conference HeritageBot 2017*, doi: 10.1007/978-3-319-67026-3_21;

[9] Milewski, R.J., et al. - *Automatic recognition of handwritten medical forms for search engines*, IJDAR (2009) 11: 203. https://doi.org/10.1007/s10032-008-0077-1

[10] Liu Y.-H. et al., *Mathematical methods applied to digital image processing*, Mathematical Problems in Engineering, vol. 2014, Article ID 480523, 4 pages, 2014;

[11] Louverdis G. et al., *A new approach to morphological color image processing*, Pattern Recognition 35 (2002) 1733–1741, Published by Elsevier Science Ltd;

[12] Wang K. et al, *End-to-end scene text recognition*, IEEE International Conference on Computer Vision (ICCV), 201110.1109/ICCV.2011.6;

[13] Cheng F., Venetsanopoulos A.N., *Adaptive morphological operators, fast algorithms and their applications*, Pattern Recognition 33 (2000) 917-933, Published by Elsevier Science Ltd;

[14] Barni M. et al., *Image processing for the analysis and conservation of paintings: opportunities and challenges*, IEEE Signal Processing Magazine, vol. 22, no. 5, pp. 141–144, 2005;