EUROGRAPHICS Workshop on Graphics and Cultural Heritage (2016)
C. E. Catalano and L. De Luca (Editors)

Toward a multimodal photogrammetric acquisition and processing methodology for monitoring conservation and restoration studies

A. Pamart [1], O. Guillon[2], J.-M. Vallet[2] & L. De Luca[1]

Modèles et simulations pour l'Architecture et le Patrimoine [UMR 3495 CNRS/MCC MAP], Marseille, France[1]
Centre Interdisciplinaire de Conservation et de Restauration du Patrimoine [MCC CICRP], Marseille, France[2]

Abstract

Close-range photogrammetry is nowadays a common technique applied to acquire 3D data on Cultural Heritage (CH) artifacts. Image-based modeling are indeed providing useful resources for the documentation and the conservation but it is also set more recently as a monitoring tool that could help the decision making in term of restoration. The 3D footprint restitutes as a point cloud, the appearance according to a definite spatial resolution and at a given time, the visible surface of an artifact. Nevertheless, different techniques of scientific imaging are also used to obtain complementary information. This paper explores a multimodal approach of the photogrammetric survey and data processing to reach a multidimensional data integration (i.e. spatial, temporal and, or spectral).

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Digitizing and scanning—I.3.6Methodology and Techniques

1. Introduction

Nowadays, the study and the follow-up of CH objects is done by the use of complementary 2D/3D scientific imaging techniques. Those techniques give the opportunity to investigate the material state of the artifact but the fusion of their respective data and possible entanglements remains challenging [BBKD*14]. Although the increasing efficiency of close-range photogrammetry for CH study, which is providing a dense and fine 3D base map, other types of scientific imaging are still needed to go beyond the visible aspect, see Figure 1. As an example, Technical Photography (TP) or computational imaging such as Reflectance Transforming Image (RTI) techniques are also used to highlight invisible chromatic or micro-geometric details. Therefore, other techniques present a slightly different sensing technologies such as hyperspectral camera (HSI), microscopy and thermal infrared (TIR) and their mutual registration remain an open-issue. As those techniques are camera-based or provide images, our work is based on the assumption of the possibility to gather them in a straightforward photogrammetric process.

2. Objective

This work is based on the statement that complementary 2D/3D imaging techniques are nowadays commonly used to enrich both documentation and analysis of CH artifact. Indeed, each techniques could provide key features – according to their spatial and spectral resolution – helping the conservation or restoration studies. Nevertheless, it leads us to collect and compile a massive and heterogeneous dataset for which useful information still need to be separately mined and analyzed. The goals of multimodality in the case of our ongoing experiments could be defined according to different aspects:

Figure 1: *High density pointcloud (60M) and high resolution (GSD = 0.3mm) from 215 images on Venasque case-study.*

- Multi-sensor; is driven by the idea of being able to gather several of data acquisition coming from different sensing technologies or imaging techniques.
- Multi-dimension; is motivated by the interest of being able to handle different spatial resolutions from macro to micro scale.
- Multi-temporal; expresses the need of being able to integrate data from different temporal states for monitoring purpose.
- Multi-spectral; follows the idea of being able to deal different spectral ranging to go beyond the visible spectrum.

DOI: 10.2312/gch.20161409

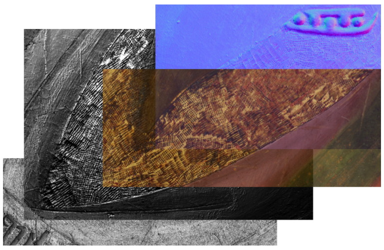

Figure 2: *Blended view of orthophotographic shaded relief map, specular H-RTI, VIS photograph and normal map.*

The challenging aspect of this project compared to related works is to reach all the multimodality aspects as stated above at the same time. The main difficulty is to face the multiple dimensions of the data acquisition and their registration into a common spatial reference system [SC13]. Indeed, the multimodal context implies some punctual adaptations of both acquisition and processing stages in order to integrate variables spectral, temporal and/or spatial resolutions of dataset. Moreover, the challenge of our approach is to rely on 2D/3D image matching only based on feature extraction in order to reach an automatic multimodal image registration without the additional support of combined methods such as Mutual Information [LBS14], [SXZJ14], [CDG*13]. The hypothesis is that the flexible photogrammetric toolchain offered by *MicMac* will give enough degrees of freedom to operate this multidimensional data fusion [DC11]. Therefore, once the data merged – into a 2D/3D multimodal continuum – the aim is to discuss and assess new possibilities in terms of cross-analysis that could help the decision making for the conservation and restoration works, as depicted in Figure 2.

3. Global Approach

A first trial of a photogrammetric data merging made from a non-dedicated multimodal acquisition pipeline shows directly some limitations especially in terms of robustness (i.e. metadata management, bad internal self-calibration, high residue). However, it leads us to understand the relevancy of the iterative and progressive data process draught and the need of the definition of an *ad-hoc* multimodal data acquisition methodology, see Figure 3 & 5.

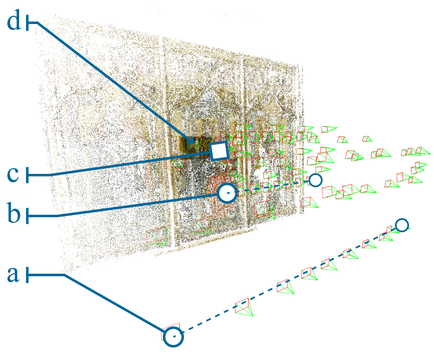

Figure 3: *Multidimensionnal blocks merged : global (a) and close-up (b) photogrammetry, multistereo H-RTI (c) and multitemporal/multispectral Technical Photography (d) on Venasque case-study.*

3.1. Data acquisition

In term of acquisition, the methodology we are defining is strongly based on a mastered high-resolution initial photogrammetric cover, especially to integrate further more demanding data (e.g. specific sensors) such as NIR camera or DinoLite microscopic imaging. A first global approach (with wide angle lens) has been done before a close-up survey (with macro lens) both reproduced with different sensors; a high-resolution (HR) full-frame CMOS 42Mpx and a high-definition (HD) APS-C layered Foveon 19Mpx. As show Figure 4, this multi-scale acquisition protocol allows to choose afterwards the spatial resolution needed (the GSD range is in between 0.5mm and 0.08mm). This initial survey was completed using different imaging techniques (TP, HSI, etc) and following experimental acquisition protocols like multispectral-RTI or multistereo-RTI using a dome. First results (see Table 1) show that this exacting photogrammetric cover was the good option to support the progressive accumulation of multidimensional data and resolve some issues of the prior unstructured trial.

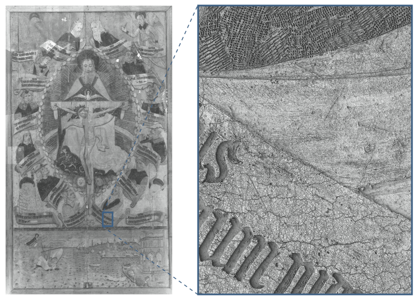

Figure 4: *Orthophotographic shaded relief map of the high resolution multi-focal photogrammetric survey with HD and HR sensors on Trinité case-study.*

3.2. Data processing

In term of data processing, the first step was to define a robust iterative pipeline enabling to merge several blocks of pictures. The advantage of our method is to reproduce the basic framework of photogrammetric registration starting from the 2D image matching (i.e. tie points extraction and pairs recognition) to the internal calibration, the external calibration and the global orientation with some tweaks. The progressive aspect appears to be one of the most important condition to respect. It means that the new block needs to be close to the dimensional aspect of the previous ones. The dimensional gap needs to be shortened to a minimum for every type of block; passing from macro to micro is helped with an additional in-between step, a temporal change must be close to the previous one, spectral addition must start by something close to the visible. The sift-points extraction has been slightly increased (using a scale factor up to 50% and Local Contrast Enhancement feature) to minimize points that will not be found because of a dimensional change. This technical income of an expanded amount of tie-points (up to 10 000) slightly decreases the impact of problematical wrong matches in the bundle adjustment. It also helps to ensure a low error of re-projection (residue) even when inter-dimensional block of images are merged using indirect imbricated orientation pipeline, as mentioned in *section 4*. In counterpart, it increases proportionally the time of computation. The global approach uses the following algorithm described below, as show in Figure 5 and still needs to be adapted according to a n-dimensional dataset :

- Create a renaming to sort and help the files management including useful dimensional information (technical specs, sensor, location index, etc) [A].
- A preliminary step might be to check, modify or create or create essential metadata for data processing[B].
- Pictures of a new block from a new dimensional state are matched [C1] then linked to other related blocks [C2].
- The new block needs to be internally calibrated whether it is coming from a new sensor and/or focal length combination [D].
- The new block is directly or indirectly externally calibrated into a reference orientation system by adapting the calibration model according to the type of data and the deviation in between the blocks [E].
- The merged block could be re-oriented to optimize their relationships to the common orientation by freezing some references poses [F].
- A new iteration from [C] step could be done on a new block by following a progressive graduation of the derivation in between the blocks [G].

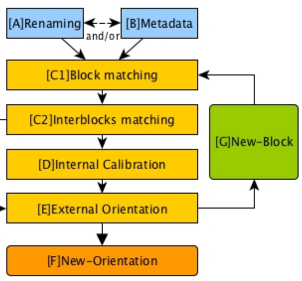

Figure 5: *Diagram of the iterative pipeline processing.*

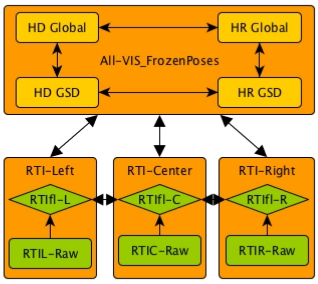

Figure 6: *Example of orientation relationships in between Multistereo-RTI data and the initial VIS photogrammetric survey.*

4. Multidimensional Approach

According to the deviation in the multidimensional dataset, our experiment shows that the different states should be gathered using an indirect orientation strategy (i.e. blocks are not merged all together but share a common relation with some frozen reference poses), as show Figure 6.

4.1. Spatial dimension

This approach aims to define a robust framework to manage different resolutions and gives the possibility to lead multi-scale observations from macro to micro. This variation is imposed by the camera specification (i.e. pitch-pixel and GSD) or could be driven during the data acquisition by modifying the optical and/or physical distance to the area of interest. A *zoom-in* method enables to densify locally the geometric reconstruction in order to point out precisely the location of samples, XRF, or LIBS analysis. To the opposite, a *zoom-out* method could be used to spatialize the area of interest into its context. Figure 7 shows a first attempt on a case-study on which a controlled acquisition permits to manage different spatial resolution from metric to sub-milimetric scale. A robust pipeline has been achieved by keeping enough overlapping in depth of the scene (at least 60%) for which the threshold could change according to the amount of tie-points.

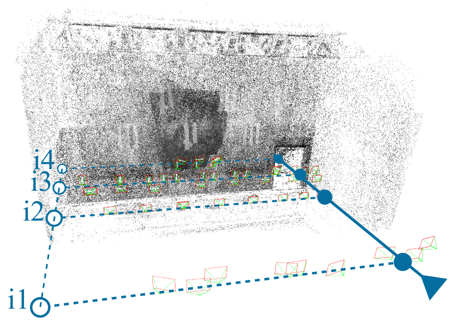

Figure 7: *Example of zoom-in multi-scale data acquisition protocol (4 iterations and 2 focal lengths) on Germolles case-study.*

4.2. Temporal dimension

This approach aims to relate different states or acquisition context in order to make possible a diachronic or synchronic (ie VIS/RAK) analysis of spatial information, see Figure 8. This approach has been defined to highlight colorimetric or geometric variations on the surface of the object. This fusion of temporal states into a common spatial reference allows to assess the evolution of degradation phenomena. Each temporal data acquisition could be reconstructed separately and compared to qualify or quantify changes [PGB*15].

Figure 8: *Example of multispectral Technical Photography (TP0 & TP2 in Table 1) merged ; VIS detail before restoration, RAK, IRr and IRfc after the restoration on Venasque case-study.*

4.3. Spectral dimension

The last approach aims to enrich a 3D digitization process by integrating multispectral imaging techniques. A first technological framework is composed of camera-based systems such as RTI or technical photography (i.e. IRr, IRfc, UVi, UVr) which have the benefit to share a photographic sensor. A second one is composed of technologies using sightly different sensors (e.g. HSI, NIR, TIR, push broom CCD) which appear to be more challenging to integrate into a photogrammetric process and will be the goal of our future works. Nevertheless, our experiment shown that it's possible to integrate multispectral images as long as there is enough similarity with the visible (VIS) photogrammetric survey. In order to surpass some of those limitations, hybrid acquisition protocols (multispectral photogrammetry with VIS, IR and UVf) has been explored as well, as shown in Figure 9 below.

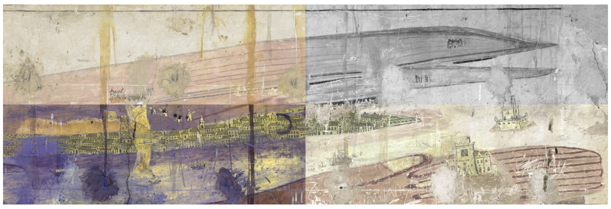

Figure 9: *Example of ad-hoc multispectral photogrammetric acquisition ; registered orthophotomosaic in visible (top-left), infraded (top-right), ultraviolet fluorescence (bottom-left) and mean composite picture (bottom-right) on Anamorphosis case-study.*

5. Conclusions

An incremental and robust pipeline using an open image-matching tool chain has been defined to the condition that data acquisition is controlled and data integration steps respect a progressive approach. Our ongoing experimentation has been successfully tested on different case-studies and shows that a multidimensional images dataset could be merged by a methodological approach of the data acquisition and processing. The first results of this multimodal photogrammetric fusion are promising as long as we succeed to gather several camera-based techniques. As show the 2D/3D multispectral continuum reached on *Anamorphosis* case-study, we prove that our image-based method is able to co-register dataset coming from *n*-dimensions (e.g. different spatial, temporal and spectral resolutions) in order to share both colorimetric and geometric attributes. Current limitations are related to the fact that the number of dimensions added and their deviations also increase the level of uncertainty in the estimation of camera positions, see Table 1. This loss of accuracy has been minimizes by the optimization of feature extraction and the indirect orientation strategy, explained in *subsection 3.2*, even if the use of MSD features extraction algorithm (Maximal Self-Dissimilarities) shall be considered. However absolute registration still could be improved by the use of a 3D laser scanning helped with control points to assess ground-truth accuracy for every iterations. Moreover technical issues still remains with the integration of non-photographic sensors and need a specific adaptation in both acquisition and processing stages (e.g. array sensor of HSI, resolution of TIR) [GARGAL12].

Iteration	Global	Close-up	RTI 60	RTI 85	TP 0	TP 2	Total
Nb. pictures	18+25	12+16	3*48	3*48	12	12	242
Spatial dim.	2	2	1	1	n/a	n/a	6
Spectral dim.	1		2		1	3	7
Temporal dim.	1				1	1	3
ER2 [*px*]	1.07	1.16	1.16	1.53	1.92	2.00	n/a

Table 1: *Results for each iteration of the multidimensional approach on a sample of Venasque case-study shown on Figures 1, 3 & 8.*

5.1. Perspectives

The definition of an efficient and robust pipeline to spatialize some scientific imaging techniques enables to focus the investigation on the cross-analysis of the multidimensional embed data. From this statement, different approaches could be carried out. One will be to explore potentials of dense matching process to bring up or highlight interesting features made possible by this hybrid photogrammetric process (i.e. changes detection, micro-geometric reconstruction). An other one will exploit this multi-layered output for an analysis based on the use tool of automatic propagation of 2D/3D semantic annotations into a spatially oriented images dataset to share and transfer dimensional information linked with scientific observations [MGLV13]. This fusion of multidimensional data through a photogrammetric process offers new perspectives to complete the complex and multidisciplinary studies for the conservation, the documentation and the restoration of CH artifacts.

Acknowledgment

This works has been supported by both the multidisciplinary mission of CNRS in the framework of FIAT-LUX project and the European Cooperation in Science and Technology, Cost-Action TD 1201, Colour and Space in Cultural Heritage (COSCH) in particular with the collaboration of Christian Degrigny leader of the "Château de Germolles" case-study.

References

[BBKD*14] BOOCHS F., BENTKOWSKA-KAFEL A., DEGRIGNY C., KARASZEWSKI M., KARMACHARYA A., KATO Z., PICOLLO M., SITNIK R., TRÉMEAU A., TSIAFAKI D., ET AL.: Colour and space in cultural heritage: Interdisciplinary approaches to documentation of material culture*. *International Journal of Heritage in the Digital Era 3*, 4 (2014), 713–730. 1

[CDG*13] CORSINI M., DELLEPIANE M., GANOVELLI F., GHERARDI R., FUSIELLO A., SCOPIGNO R.: Fully automatic registration of image sets on approximate geometry. *International journal of computer vision 102*, 1-3 (2013), 91–111. 2

[DC11] DESEILLIGNY M. P., CLERY I.: Apero, an open source bundle adjustment software for automatic calibration and orientation of set of images. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 38*, 5 (2011). 2

[GARGAL12] GONZÁLEZ-AGUILERA D., RODRIGUEZ-GONZALVEZ P., ARMESTO J., LAGÜELA S.: Novel approach to 3d thermography and energy efficiency evaluation. *Energy and Buildings 54* (2012), 436–443. 4

[LBS14] LANARAS C., BALTSAVIAS E., SCHINDLER K.: A comparison and combination of methods for co-registration of multi-modal images. In *Proceedings of 35th Asian Conference on Remote Sensing, Nay Pyi Taw, Myanmar* (2014), vol. 2731. 2

[MGLV13] MANUEL A., GATTET E., LUCA L. D., VÉRON P.: An approach for precise 2d/3d semantic annotation of spatially-oriented images for in situ visualization applications. In *Digital Heritage International Congress (DigitalHeritage), 2013* (Oct 2013), vol. 1, pp. 289–296. doi:10.1109/DigitalHeritage.2013.6743752. 4

[PGB*15] PETELER F., GATTET E., BROMBLET P., GUILLON O., VALLET J.-M., DE LUCA L.: Analyzing the evolution of deterioration patterns: A first step of an image-based approach for comparing multitemporal data sets. In *2015 Digital Heritage* (2015), vol. 2, IEEE, pp. 113–116. 3

[SC13] SIMON CHANE C.: *Intégration de systèmes d'acquisition de données spatiales et spectrales haute résolution, dans le cadre de la génération d'informations appliquées à la conservation du patrimoine*. PhD thesis, Dijon, 2013. 2

[SXZJ14] SHEN X., XU L., ZHANG Q., JIA J.: Multi-modal and multi-spectral registration for natural images. In *European Conference on Computer Vision* (2014), Springer, pp. 309–324. 2