ENHANCING TERRESTRIAL POINT CLOUDS USING UPSAMPLING STRATEGY: FIRST OBSERVATION AND TEST ON FARO FLASH TECHNOLOGY

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ABSTRACT:
Nowadays 3D digitization through the combination or hybridization of different sensors, with the final aim of accelerating the phases of data acquisition and storage, develops user friendly and robotics systems, making efficient the operator role. New technologies as Hybrid Reality Capture™ (HRC), with Flash Technology (FARO Tech.) certainly fits into this market trend, and it is characterized by rapid acquisition, involving 3D scanning data with panoramic images contribution. The system is still under patent, and nothing is yet released on the technology. This research presents the analysis and discussion of results based on the raw and processed data related to the new FARO system. The assumption – based on the information declared by the manufacturer (FARO, 2023) – is that the new colored Flash scans are faster and denser than scans of the same resolution obtained using traditional static scanning method, due to the crucial contribution of the PanoCam data and resolution on which the upsampling strategy is based. An evaluation based on detailed analysis of the upsampling results is reported, delivering that the surface point density exponentially decreases with the distance and with the ray incidence inclination. A comparison with a mobile mapping technology is finally presented and discussed.

1. INTRODUCTION

For many years, research and consequently the measurement systems market make users familiar with the continuous development and offers of increasingly automated solutions, which optimize 3D digitization through the combination or hybridization of different sensors, with the final aim of accelerating the phases of data acquisition and storage, making user friendly the use of the system, when these solutions do not seek to replace the operator via robotic systems.
According to this trend, FARO Technology is developing and presenting to the user community a new solution combining the series S Faro Scanners with the new Hybrid reality capture (HRC) release coupled with a panoramic camera: this solution allows acquisitions of ultra-fast point clouds, with a lower density than the corresponding classic clouds from static acquisitions, and produces a final cloud comparable in density to the standard one, exploiting an upsampling technique called flash technology connected to the simultaneous pano-camera image acquisition.
Although FARO technology is still under patent, and nothing has yet been released on the technology, the research group has had the opportunity to observe and assess these data with the purpose of highlighting limitations and potential in the heritage sector. In fact, the system declares its limits of applicability for large project with wide areas, bottlenecks, great details, high fidelity, as well as potential. The aim of this research tries to verify and validate them in the heritage building complexes context.
The preliminary investigation wants to assess the new FARO HRC Flash Technology and the system performance in an indoor-outdoor heritage complex scenario. As a first step, the research focuses on the porch and courtyard area of the Royal Palace in Turin (Figure 1).

1.1 Upsampling strategies: promising perspective

The problem of increasing image resolution and point cloud resolution and density is crucial in many application sectors; Traditionally, in the mapping realm, the need to apply upscaling techniques has been much investigated to address the problem of spatial resolution of satellite images for their use with remote sensing techniques. (Riihimäki et al., 2019, Ajmar et al. 2017)
Furthermore, in the field of security and surveillance from image-based systems, the problem of deriving high-resolution (HR) images from low-resolution images (LR) exploiting Super-Resolution (SR) models has undergone an extraordinary development, also in the direction of strategies for recognizing people (person Re_Identification) from surveillance cameras. (Hauptmann et al. 2016)
In this framework, many advances were able to benefit from advanced network structure and deep learning strategies (Zhang et al. 2021; Li et al. 2019, Charles et al. 2017), and also many studies address the problem of different image resolution by employing cross-resolution approaches. (Jiao et al. 2018).
Taking a step back, it can be said that the point cloud upsampling algorithms took advantage of previous research on those intended for image upscaling, which is a typical computer vision problem, and a general classification of solutions exploiting different approaches can be as follows:

- Deep learning-based super-resolution methods (Kim & Lee, 2018);
- Random forests recognised as highly non-linear learners that can handle high dimensional noisy inputs (Schulter et al. 2015).

One of the substantial differences that exist between the problem of increasing the resolution of single images and point clouds is that the 3D cloud is very different from a 2D grid since clouds derived both from Lidar or image-based techniques always present scattered points with the non-regular spatial distribution.
If the criticalities of upscaling in the field of images can be linked to camera settings, points of view, lighting problems and background changes, the point clouds upsampling strategies must face both similar problems possibly related to the sensors, as well as any possible moving objects, the shooting distances and most of all problems connected to the morphology of the scene that has a great influence on the cloud noise which is one of the most relevant challenging issues.
Furthermore, the cloud generated by the upsampling technique must necessarily continue to effectively describe the reference surface (object) represented by the cloud. Therefore, the issue is

surely more complex than a simple interpolation, which is definitely not sufficient (Yu et al. 2018).
As will be better deepened in the following paragraphs, if cloud densification is a widely addressed problem, the most challenging issue is, above all, when densification involves an increase in the level of detail of the cloud, and therefore also a problem of defining the edges of the surfaces.
However, a very important issue to consider is that the raw point cloud data significantly benefit from upsampling techniques, thanks to the noise decrease and the greater uniformity of the cloud obtained, which means the more regular spatial distribution of points enables or helps further processing that the cloud may be subjected to.
In fact, the use of such optimized point clouds is required or welcome in many different directions such as classification, detection and segmentation of 3D surfaces. (Zhang et al. 2022)
Precisely Zhang et al. (2022) allow a clear and critical framework of the many different attempts to solve the upsampling problem, classifying in their review the methods developed so far into optimization-based point cloud upsampling and deep learning-based point cloud upsampling, the latter both supervised and unsupervised (Figure 1).

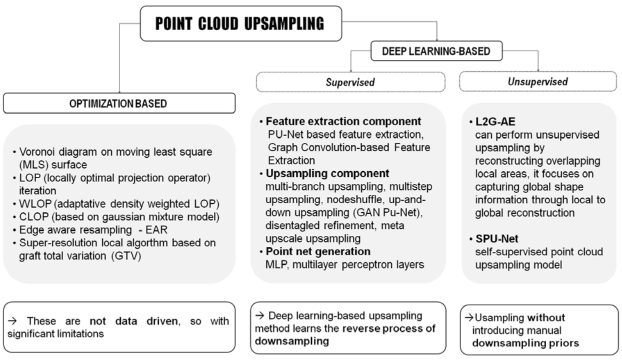


Figure 1. Synthesis of the classigfication of upsampling approaches (Zhang et al. 2022)

Referring to the diagram in Figure 1, which we produced on the basis of Zhang's reflections, regarding the left column, since optimization-based methods are not based on a data-driven approach, they require a priori data such as the evaluation of the normals and they rely on the regularity of the object surface, so they present a number of limitations. This is one of the most relevant reasons for developing alternative and most effective solutions, such as deep learning-based methods (right both columns). Among supervised and unsupervised methods, the first category relies on network training learning from the downsampling process, while unsupervised upsampling solutions don’t need priors downsampling manually conducted, so in this perspective, they are preferred. (Zhang et al. 2022).
Lastly, we would like to cite a couple of strategies that propose workflows combining point cloud upsampling in combination with image-based integrations or fusion-based solutions, since the new solution by Faro exploits the pano camera images to reach the results.
The first one, from Nguyen et al. 2022, suggests combining raw point clouds with being upsampled in combination with 2D images from which they extract more information with the use of a generative Adversarial Network (GAN) in the training and testing phase. This method has been applied to the detection and segmentation of cracks patterns, for example, pertaining to bridges, buildings, or other infrastructures coming from the construction sector, so very close and relevant to the domain the present paper focuses.

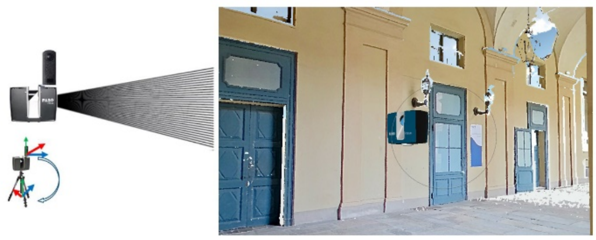
Moreover, other starting points from strategies aimed at the same objectives and applied in neighboring fields, as well as already very settled, come from (Park et al. 2011) who studied the possibility of improving the resolution of point clouds acquired by TOF 3D cameras, notoriously characterized by low resolution, improving the edges of objects in depth maps using high resolutions RGB inputs.

2. METHODOLOGY

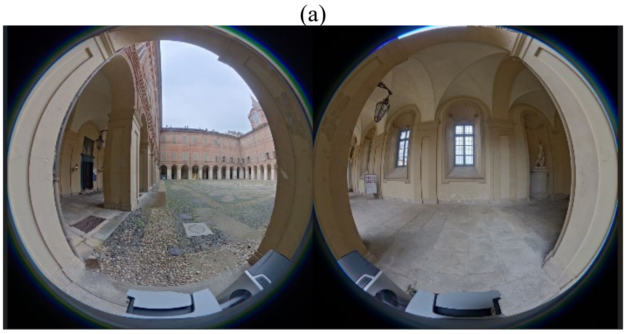
The research aim is to evaluate the performance of the Flash Technology (FARO Tech.) system – based on the collection of short and low-resolution static scans processed with an upsampling algorithm – in terms of acquisition efficiency and delivered final data. The assumption – based on the information declared by the manufacturer (FARO, 2023) – is that the new colored Flash scans (Figure 2) are faster and denser than scans of the same resolution obtained using the traditional static scanning method, due to the crucial contribution of the PanoCam data and resolution – equipped on the system – on which the upsampling strategy is based. This feature represents a groundbreaking advancement since it allows to acquire high-resolution data – characterised by geometric definition and level of detail comparable to traditional data – with a significant time saving from an acquisition and processing perspective.

2.1 The scanning system method

The Hybrid Reality Capture™ (HRC), with Flash Technology (FARO Tech.), certainly fits into the introduced market trend of sensors hybridization and data acquisition phase acceleration.
Compared to the previous data collection technology, the Flash Technology has been implemented as an optimization of both acquisition rapidity and data precision and quality (FARO, 2023).



(a)



(b)

Figure 2. (a) Preview of a collected Flash scan; (b) Spherical image acquired with Panocam.

The so-called Flash scanner system (Figure 2) is characterized by a speed of 10 seconds and coupled with a panoramic camera (less than 30 seconds of data capturing, considering both range and image data), direct traditional TLS technologies towards the speed of mobile systems (MMS) based on portable scanners. This has already been faced by (Bonfanti et al. 2021) for the FARO

Swift scanner, as an evolution of the traditional terrestrial laser scanning approach. New Flash tech. is undoubtedly interesting because it combines rapid acquisition, involving horizontal scanning angular step of 10" with the panoramic images contribution. This allows the implementation of an upsampling strategy to the point cloud which the present research tries to investigate and describe.
Specifically, during the data acquisition, the scanning plan is managed by the operator through a mobile device (e.g., tablet) where it is possible to assist and operate, if necessary, a semi-automatic visual pre-alignment based on the scan's positions and scanner movements.
This introduces an improvement also for the time-consuming subsequent registration phase. In the processing phase, subsequently, the upsampling algorithm (under FARO patent) is the solution for the point cloud density and colour content. Here a crucial role is played by the PanoCam, integrated into the scanner and whose centers have been calibrated in order to associate radiometric content to the scan data and mainly, as declared, to improve point density: the camera is the Ricoh Theta Z1 360° (7296*3648px resolution) (Figure 2b).
The capturing technology is based on an extremely faster acquisition phase, as introduced, and a hybrid scan processing exploiting both the low-resolution raw scans and the high-resolution PanoCam images contribution (Figure 2b). The acquisition parameters for the Flash scans, according to the consolidated FARO settings, are (2x) quality and (¼) resolution, that correspond to declared point spacing 6mm@10m.

2.2 Flash data processing

The scans project is based on a first calibration scan in higher quality, ensuring the accuracy of hybrid LiDAR-panoramic data acquisition. In the registration phases, it is allowed to exploit ICP-based and target-based approaches too for accuracy control. The point cloud preview is visible in Figure 3. The overall statistics are: ICP-quality = 1.5 mm (83% points deviation <4mm) and Markers-quality mean error=11 mm, (st.Dev=4mm). In Figure 4 an example of a orthophoto valorising the high quality radiometric data.

Figure 3. Flash point cloud of the Royal Palace's cloister.

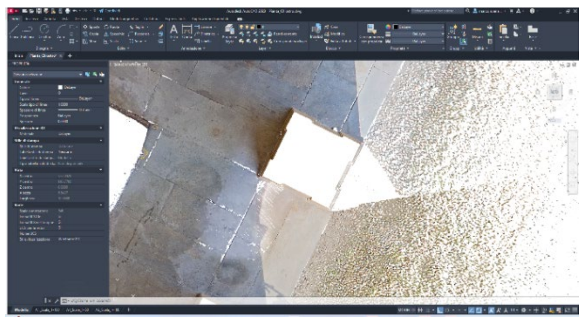
Figure 4. Orthophoto derived from Flash point cloud.

3. RESULTS AND ANALYSIS

The results analysis and discussions will be oriented toward different points of view and based on the output data analysis and a first-step point cloud assessment. In these directions, many considerations can be addressed in order to understand the results of the upsampling algorithm.
Based on the conducted analysis, one of the most important aspects affecting the upsampling performance is the scan acquisition configuration: scan position, distances and rays' directions, according to the digitized surfaces, as clearly visible in Figure 5. Actually, the effectiveness of the upsampling algorithm implemented with the Flash tech. depends on the relationship between the angular resolution (par. 3.1) and the surface orientation with respect to the angle of incidence dimensions (par. 3.4) and, of course, of the detail to be detected.

(a)

(b)



(c)

Figure 5. The courtyard façade in different visualization: (a) the scan planar preview, (b) the farther surface from the scan position, and (c) the different upsampling performance on foreshortened (façade) and reduced inclination (arches).

3.1 Scan pattern density: expected VS measured

The first aspect to be considered in detail is the characteristic of pattern for the final Flash point cloud. The test will compare the declared pattern density with the output data resolution and size. A single raw Flash scan consists of almost 25mln points and 500Mb, compared to a generic static one, of 45mln points per 700 Mb. For a Flash scan, the declared planned pattern density is 1918*4267 points (for a ¼ res.). This, although, corresponds to a final scan resolution of about 8000*3300 points per scan (according to the angular step, almost 0°3', Par. 3.2).

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This final resolution is thus comparable to an approximately 25mln points scan analysed in this project, and not 8mln points expected from the pattern density (Table 1).

From scanner Spec (metadata)	**After Upsampling** (export data)
1918*4267	8000*3300
~ 8 mln points	~ 20-25 mln points

Table 1. Table with the comparison between the resolution parameters as reported in the scanner metadata and the resolution of the point cloud after the upsampling.

3.2 Point cloud angular spacing

Considering the declared angular measurement, for traditional and Flash scans, the density analysis has been thus conducted firstly for angular spacing (Par. 3.2) and then for surface density (Par. 3.3.).

If the starting scans parameters are equivalent (¼ resolution, 2x quality), a standard FARO Focus scan reports a point density of 6mm@10m (These values are declared by manufacturer. However, there are no indications regarding the same density values of the Flash technology scans). In fact, in the Flash the empirically verified data is almost 8mm@10m (Figure 6) an in Table 2 a systematic analysis of angular spacing at different distances.

Distance	**Angular spacing** (°)	**Surfaces points spacing** (*mm*)
1.5m	~ 0°3’	~1.5mm
5m	~ 0°3’	~5mm
10m	~ 0°3’	~8mm
10m (foreshortened)	~ 0°3’	~15mm
50m	~ 0°3’	~40mm
70m (foreshortened)	~ 0°3’	~260mm

Table 2. Angular spacing values at fixed distances in terms of angles (°) and point spacing (mm).

Figure 6. The setup of the 3D points spacing analysis

3.3 Point cloud density

A significant aspect that considerably affects the densification process derived from the upsampling algorithms implemented in the analysed scanning system is represented by the acquisition distance. This is evident by observing the comparison between the density analyses carried out on point clouds acquired with the laser scanner placed at different distances from the analysed surface, considering both the traditional static method – as the ground truth model – and Flash acquisition.

The first comparison is between a couple of scans acquired in the middle of the cloister, where the measured surfaces are located at the greatest distance from the sensor during the scanning process. A density analysis has been carried out using the number of neighbour method (for each point, a sphere of 0.03 m has been computed, evaluating the number of points inside the sphere). As expected, the number of points in the traditional scan is significantly higher – approximately double – compared to that of the Flash scan (traditional scan: approximately 27 mln of points; flash scan: approximately 15 mln of points) and consequently, the density of the two scans has a ratio of approximately 1:2, as observed in Figure 7. In both scans, the density variation exhibits a radial behaviour and is mainly influenced by distance: the closer areas – specifically, the surface of the flooring to the instrument during the acquisition – are denser both in the static scan and the Flash scan, as expected. Additionally, regarding the more distant surfaces (in this case, >30 m), despite the lower density the traditional scan manages to capture some architectural details (e.g., mouldings, window elements, etc.) whereas the Flash point cloud is sparser and a higher number of gaps can be observed, especially where the incident angle of the laser beam is greater (as it is possible to observe in Figure 8). This indicates that the employed upsampling algorithm is less effective at medium to long distances.

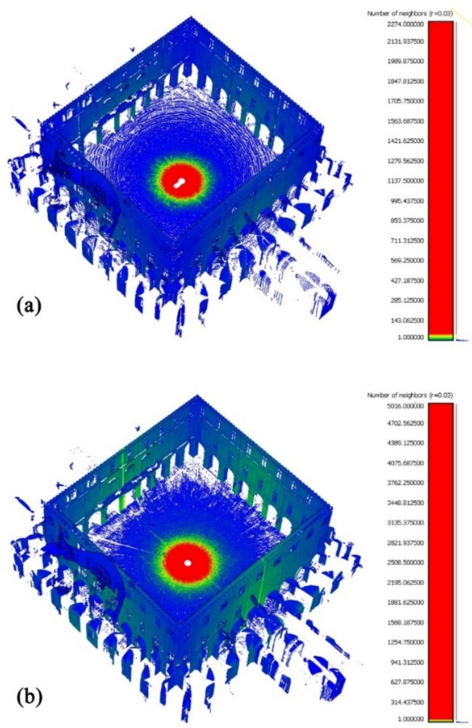


Figure 7. Density analyses carried out on the scans acquired in the center of the cloister: (a) Flash scan; (b) Traditional static scan.

A second test has been carried out with the aim of evaluating the upsampling behaviour on surfaces located at shorter distances. Therefore, two scans acquired under the vaults of the porch have been considered for this analysis. Again, it emerges that the Flash point cloud is composed of a significantly lower number of points (traditional scan: approximately 36 mln of points; flash scan: approximately 21 mln of points) but in this case the area where a higher density of points is observed belongs to the Flash scan. In fact, as it is possible to observe in Figure 9a and b, in the proximity of the laser scanner position, the density between static scan and Flash scan is comparable. It is also important to emphasise that in the area where the higher density is observed (the surface of the vault above the laser scanner during the acquisition), the Flash scan surpasses the traditional scan with a ratio of approximately 3:1, noticing in the higher point a density of more than 20,000 pts/V sphere r = 0.03 m. This phenomenon demonstrates, as stated by the manufacturer, that this technology – and consequently, the implemented upsampling algorithm – performs better and allows for obtaining denser and geometrically defined results at short distances, while this technology becomes less effective in the densification task as the distance and the angle of incidence of the laser beam increase.

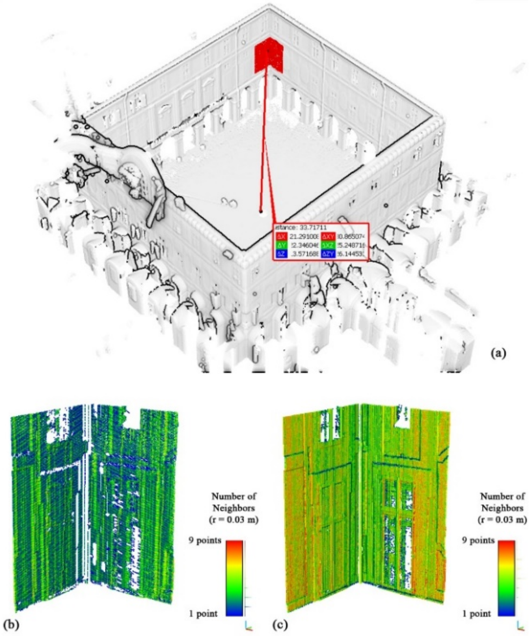


Figure 8. (a) Position of analysed surfaces (b) Detail of the density analyses carried out on the Flash scan acquired in the center of the cloister; (c) the density analyses carried out on the traditional static scan acquired in the center of the cloister.

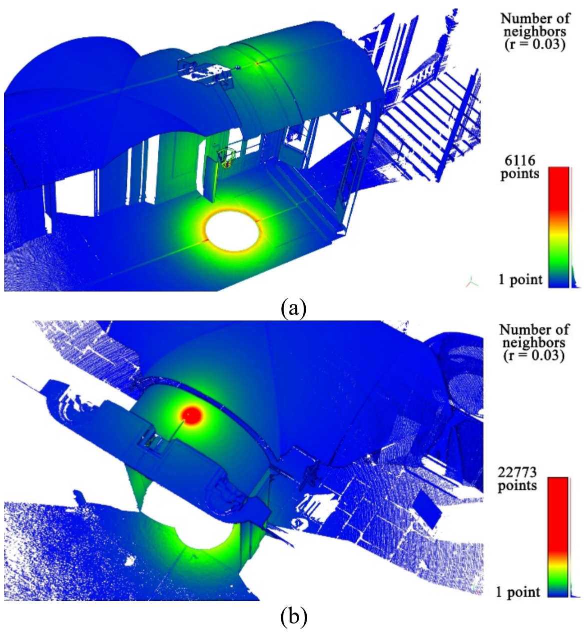


Figure 9. Density distribution analyses carried out on the scans acquired in the porch: (a) static one, under the vaults of the cloister, (b) flash scan, under the porch arch.

3.4 Point cloud resolution performance

It has been analysed that the upsampling performance is better where no strong edges are detected on the surveyed surface. In the case of corners, as expected, the reconstructive behaviour struggles to generate dense detail with respect to the plane. Furthermore, also the shape and extension of the geometry to be measured also make a difference in the details result: since the vertical spacing is different from the horizontal, there are different behaviours in relation to vertically-developed objects compared to horizontally-extended ones.

In fact, the Flash scan project has been organized and performed according to a global uniformity of coverage and density, taking into consideration scans position, distances and rays' inclination and to study their influence on the upsampling algorithm.

It is now interesting to evaluate how the surface density is influenced by the ray incidence on objects. For this reason, the following analysis has been carried out with the aim of stressing and evaluating the variation – in terms of performance – of the upsampling algorithm as the incident angle of the laser beam changes with respect to the detected surfaces. Different Flash scans have been considered and the acquired surfaces have been analysed in terms of completeness, focusing on the facades of the porch. This is due to the fact that, as stated by the manufacturer (which declares that this strategy is particularly suitable for surveys carried out at short range), the most challenging surfaces to reconstruct are those located at a greater distance from the sensor (45-65m). In Figure 10 (scan022, in the upper porch corner), Figure 11 (scan015 in the right part of the porch) and Figure 12 (scan010 acquired in the middle) it is possible to observe how the acquisition pattern, result of the upsampling patented algorithm, varies – in terms of geometric completeness – with the movement of the relative position of the laser scanner.

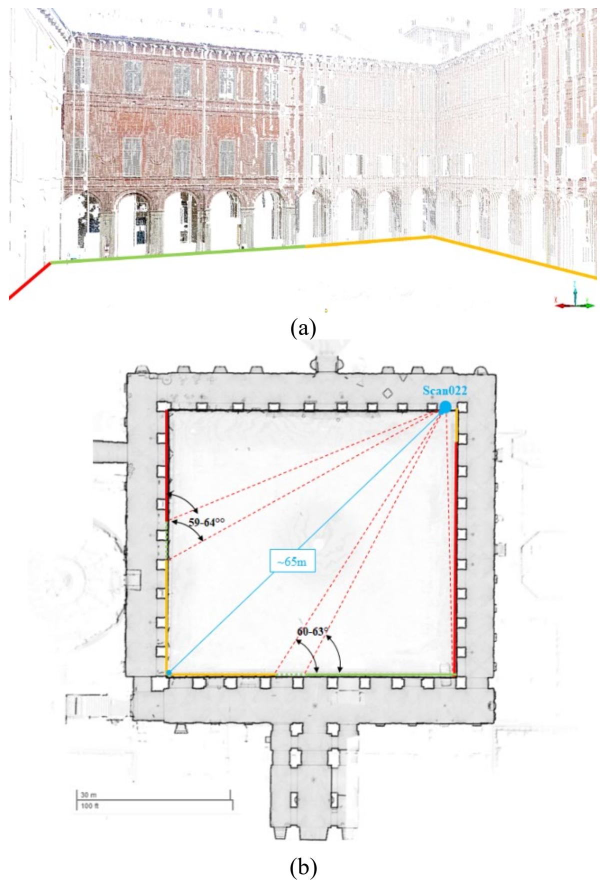
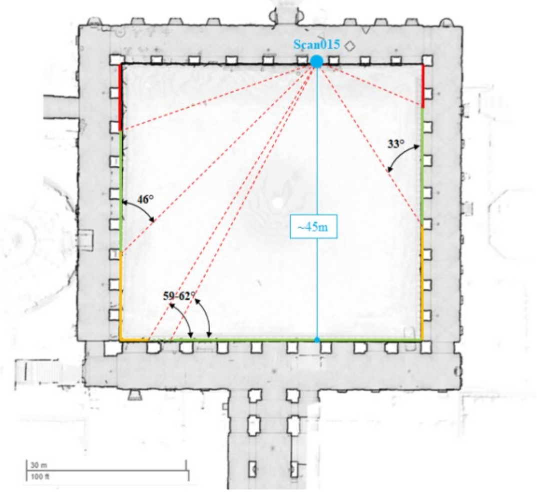


Figure 10. (a) Flash scan 3D view; (b) Analysis carried out on the scan acquired in the 022 position.

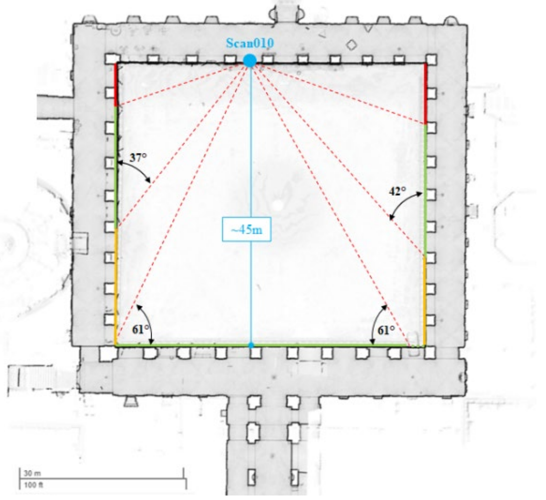
(a)



(b)

Figure 11. (a) Flash scan 3D view; (b) Analysis carried out on the scan acquired in the 015 position.

(a)



(b)

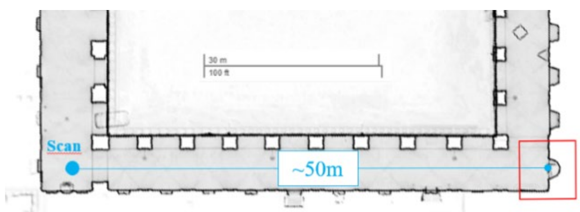
Figure 12. (a) Flash scan 3D view; (b) Analysis carried out on the scan acquired in the 010 position.

Specifically, the areas where the point density is higher and the geometric definition of the façade is comparable to a traditional TLS point cloud are evidenced in green. Areas evidenced in yellow are those where a significantly lower density is observed despite the acquisition distance being comparable or equal to the neighbouring surfaces (Areas in red are expected occlusions generated by the pillars of the porch, for the single scan position). From a visual inspection, it is immediately evident that there is a significant correlation between the sensor position and the orientation of the measured surface, particularly in terms of façade orientation with respect to the incident laser beam.
When the orientation of the façade is perpendicular (frontal position) to the sensor signal, the most complete results – in terms of geometric reconstruction – are observed in a specific angular range (approximately) between 60° and 90°, verified in different cases. As the inclination of the surface increases (becoming evident on the facades located laterally to the laser scanner position), the data becomes sparser and scarcer. In this case, it is observed that the best reconstruction performs when the angular value between the incident laser beam and the analyses surfaces falls within a range higher than 30°-40°.

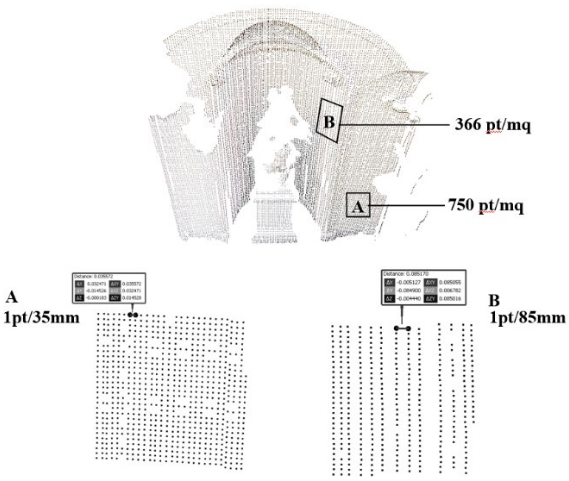
This aspect becomes further evident from the local analyses carried out on different samples (dimension of samples: 1m x 1m) with the aim of evaluating the algorithm performance at fixed distances. In fact, the surface point density exponentially decreases with the distance and with the ray incidence inclination.
Two ranges have been considered: 10m (short) and 50m (medium range) (Figure 13a). Regarding the density values – observed in samples analysed at 10m – are the following:

• 16954 points/m^2 @10m (orthogonal direction of the laser beam on the analysed sample);
• 9206 points/m^2 @10m, (foreshortened direction of the laser beam on the analysed sample).

As evident from these values, the orientation of the object acquired by the laser beam heavily affects the density of the final point cloud. In this case, foreshortened objects are characterised by a density which exhibits a ratio of 1 to 2 in comparison to orthogonal surfaces.
This is even more evident when observing the distribution of the points extracted from the samples acquired at 50 m (in this case, a semi-circular niche containing a statue was considered, Figure 13a). In Figure 13b, when the surface is approximately perpendicular (eg., the wall adjacent to the niche), the density of the points and the quality of the geometric reconstruction are comparable to the sample extracted in the same position from a traditional TLS point cloud (in both cases the observed point spacing is approximately 35-40 mm).
However, in Figure 13c it is visible that the upsampling algorithm completely failed to reconstruct the inclined and curved areas of the niche, with point spacing > 40 cm. However, the only area of the semi-circular niche where the surfaces have been properly measured is the central area with the incident angle is almost 90°.



(a)



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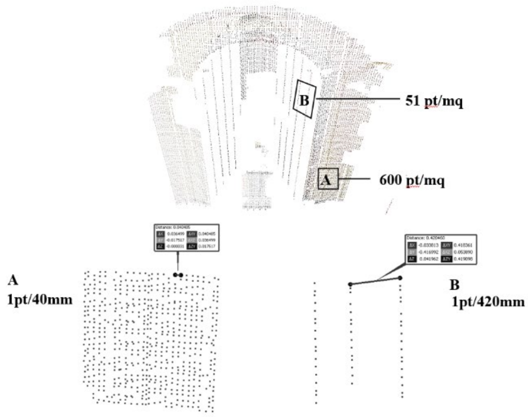

(c)

Figure 13. The porch apse, (a), visualized on a scan in the opposite (b) FARO static, (c) FARO Flash.

4. DISCUSSION: A NEW MMS SOLUTION?

One of the undeniable advantages associated with the use of this FARO Flash method concerns the optimization of efficiency compared to the traditional TLS approach. In connection with this concept of acquisition rapidity, the recent trends in the MMS domain should be considered in this case, discussing this new technology. Regarding rapid mapping strategies aimed at architectural 3D sensing and documentation, a predominant role is played by the use of mobile SLAM-based solutions, which are capable of ensuring performance efficiency to document architectural scale – despite the nominal accuracies of these instruments usually being lower than traditional static LiDAR solutions – with reduced acquisition time.

Considering the acquisition speed as a crucial parameter for evaluating the Flash system, the presented research includes a comparison between a point cloud acquired with a SLAM-based system and the point cloud derived from the short static scans. For this reason, the vaulted porch of the cloister has been surveyed using a SLAM-based mobile scanning system (Stonex ® X120GO) (Martino et al. 2023; Tanduo et al. 2023). A coloured point cloud – the system is equipped with three 5 MP cameras in order to provide radiometry to the acquired scans – has been therefore collected. Subsequently, the data derived from the employed scanning systems have been co-registered in the same reference system using (using an ICP-based algorithm) and compared. The main differences between the used systems – and the derived primary data – can be identified as follows:

- *Density of the collected point clouds.* The point cloud derived from the MMS is composed by ca. 50 mln of points, while the Flash point cloud (before proceeding with decimation and filtering procedures) is composed by ca. 1150 mln of points (for this comparison, only the scans acquired under the porch's vault and covering the same surfaces of the path followed by the MMS have been considered). The Flash point cloud is significantly greater and denser than the MMS one, if the architectural scale application requires higher detail. However, is often necessary to properly plan a tailored data acquisition strategy to optimize amount of data collected and filter and eliminate redundant points, thereby improving data manageability;
- *Acquisition time*. The acquisition of the point cloud collected with the Stonex®120GO required approximately 5-10 minutes while, regarding the Flash technology, during the scanning operations 47 scans were collected and the time required was approximately 45-60 minutes. Despite the strategy related to the use of Flash scans being extremely competitive in terms of acquisition speed compared to a traditional terrestrial laser scanning method, in this case, the time required by the Stonex ® 120GO system is significantly lower. This emphasises how one of the main features that has made scanning systems belonging to this family increasingly popular in the field of architectural metric surveying is the decisive optimisation required time for the acquisition phase.
- *3D metric accuracy.* After a discrepancy analysis performed between the considered data, it can be observed that 97.6% of the analysed points are characterised by deviation lower than ±0.02, evidencing how both point clouds are – from a metric accuracy perspective – consistent with the requirements needed for architectural-scale documentation. (Figure 14).
- *Level of detail/geometric definition.* From (Figure 15) it is possible to observe how the Stonex system was able to detect the main surfaces and architectural elements of the porch, but the level of spatial resolution which characterises the Flash point clouds is significantly higher – comparable to the one achieved by traditional static scans – and in comparison, with the MMS, this data effectively described the details and elements belonging to the decorative apparatus.
- *Radiometry*. Despite the recent trend in the development of SLAM-based MMS, which has increasingly moved towards the possibility of providing radiometry to the point clouds collected with Flash technology by implementing digital cameras in the acquisition systems, in this case the visual comparison between the two-point clouds (Figure 16) reveals that the Flash point cloud, enriched with images acquired with the Panocam, provides a significantly better result in terms of radiometric quality (also visible in Figure4).

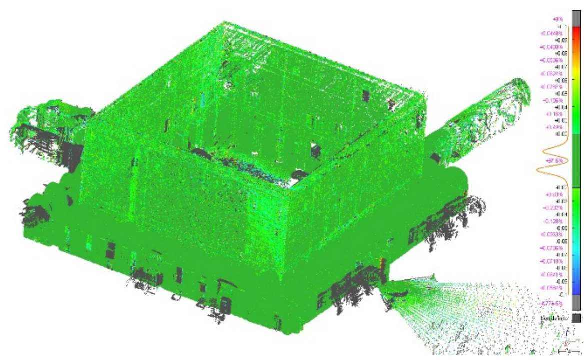

Figure 14. Cloud-to-cloud discrepancy analysis between MMS data and Flash data.

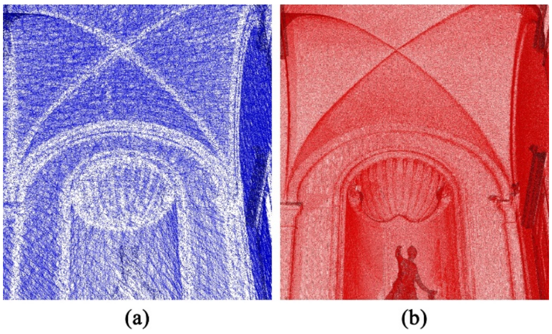

Figure 15. Visual comparison between the two analysed scans. (a) Detail of the point cloud acquired using the slam-based scanner Stonex ® X120GO (portion of the vaulted porch and elements of the decorative apparatus); (a) Flash scan.

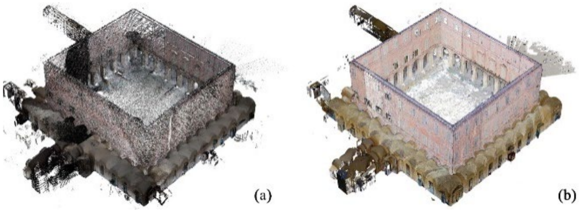

Figure 16. Point cloud acquired using (a) the slam-based scanner Stonex ® X120GO; (b) the Faro Flash.

5. CONCLUSIONS AND PERSPECTIVES

In conclusion, the research presents the exploration of the new Hybrid Reality Capture™ (HRC), with Flash Technology (FARO Tech.) as a benchmarking of the scanning system approaches in indoor/outdoor heritage contexts. It also propose a comparison with consolidated static FARO scans typology and a SLAM-based mobile mapping data. The research evaluated and summarize the main performances of the system in terms of final 3D data, examining in particular the results of the new upsampling algorithm based on hybrid LiDAR and Panocam data equipping the scanner. Different factors are related to the upsampling performance, influencing quality, density and continuity of the final 3D data: scan position and distance from the object; LiDAR rays' incidence on the surfaces and quality of radiometric data. This is undoubtedly a up-to-date promising technological improvement in direction of hybridization of sensors, automation in procedures and speediness of site survey. Nevertheless, as introduced, the algorithm at the bases of this such powerful upsampling is still under FARO patent.

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