Application of handheld mobile terrestrial laser scanning for cultural heritage documentation.

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ABSTRACT

The preservation and documentation of cultural heritage sites are fundamental to safeguarding our shared history and identity. This study explores the innovative application of the viDoc RTK rover for cultural heritage documentation, presenting a forward-looking approach to capturing high-precision spatial data in the preservation and analysis of Brari bridge located in Tirana, Albania. Handheld mobile terrestrial laser scanning (HMTLS) offers versatility and mobility, enabling rapid and non-invasive data acquisition in complex and challenging environments. The methodology encompasses equipment selection, data acquisition techniques, and data processing workflows tailored for HMTLS technology. The results demonstrate the potential of HMTLS to produce highly accurate 3D models, showcasing intricate architectural details and capturing fine surface textures with an accuracy of 3 cm. Furthermore, the portability of handheld devices allows for documentation in areas where traditional scanning methods may be impractical. This study underscores the transformative impact of HMTLS on cultural heritage preservation, offering a cost-effective, efficient, and accessible means of creating digital archives. The adoption of this technology contributes to the long-term conservation, research, and education associated with our cultural heritage, ensuring that these invaluable assets continue to inspire and inform future generations.
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Keywords: Accuracy, heritage, Point Cloud, Terrestrial Laser Scanning, HMTLS.

1. Introduction

In the ever-evolving landscape of cultural heritage documentation, the emergence of cutting-edge technologies has propelled the field into a new era of precision and efficiency. Among these technological marvels, handheld mobile terrestrial laser scanning stands out as a transformative force, redefining the way we perceive, analyse, and ultimately safeguard our cultural legacy.

This innovative approach combines the prowess of terrestrial laser scanning with the freedom of handheld mobility, offering a dynamic solution to the challenges inherent in documenting the intricate nuances of historical sites, artifacts, and structures.

Historically, the preservation and documentation of cultural heritage have relied on traditional surveying methods that often proved to be time-consuming, resource-intensive, and constrained by their limitations in capturing intricate details.

Enter handheld mobile terrestrial laser scanning, a revolutionary technology that addresses these challenges by seamlessly blending accuracy with portability. This advancement allows researchers, archaeologists, and preservationists to navigate and scan diverse and often challenging terrains with unprecedented ease.

At its core, handheld mobile terrestrial laser scanning involves the use of a portable device equipped with laser scanners to capture highly detailed, three-dimensional representations of the environment.

This method facilitates the rapid and comprehensive documentation of cultural heritage sites, artifacts, and structures, offering a level of detail and accuracy that was once unimaginable. The handheld nature of the device further empowers practitioners to explore and document spaces that were previously inaccessible or difficult to survey using traditional stationary laser scanning methods.

The applications of handheld mobile terrestrial laser scanning in cultural heritage documentation are manifold. From archaeological excavations to architectural surveys, this technology provides a versatile toolset for capturing the physical manifestations of our shared history.

The three-dimensional point cloud data generated by these scanners not only preserves the geometric intricacies of cultural artifacts but also serves as a foundation for creating detailed digital reconstructions. This digital documentation proves invaluable in research, restoration, and conservation efforts, offering a non-invasive means to analyze, monitor, and preserve cultural heritage resources.

Moreover, the real-time nature of handheld mobile terrestrial laser scanning enables practitioners to adapt to the dynamic nature of cultural heritage sites. Whether capturing the fine details of a delicate artifact or documenting the structural integrity of an ancient building, the flexibility of this technology allows for a level of responsiveness and adaptability previously unattainable.

As we delve into the realm of handheld mobile terrestrial laser scanning for cultural heritage documentation, this exploration will uncover the myriad benefits, challenges, and ethical considerations surrounding its application. From its role in democratizing access to cultural heritage information to the implications for future research methodologies, the impact of this technology on the preservation and understanding of our cultural legacy is both profound and far-reaching.

Through this comprehensive examination, we embark on a journey into the intersection of technology and cultural heritage, where innovation becomes a catalyst for unlocking the secrets of the past while shaping the future of preservation.

1.1. Case Study

This introduction sets the stage for a profound exploration of the application of handheld mobile terrestrial laser scanning, with a specific focus on a compelling case study: the Brari Bridge. Beneath the village of Brar sits the Brari Bridge, which crosses the Tirana River. Typologically speaking, it symbolizes the bridge with a circular vault.

This bridge is a representation of a two-stage-built stone bridge with a round arch. The bridge's cobblestones were steeper during its initial phase at the start of the eighteenth century. This slope was later lessened by the addition of walls on both sides.

Single-arch stone bridges are the simplest bridges to build and were built mostly across small streams and rivers. Being small and not technically difficult from the point of view of construction, single-arch bridges are encountered not only on the important roads of the time, but also in villages and isolated areas.

Figure 1. "Brari Bridge", Tirana.

The bridge is located in the village of Brar in Tirana County. Built in the 18th century AD on the ruins of an old Roman bridge is a single-arch stone bridge dating back to the Ottoman era. A cultural monument of 1st category. What is interesting is that the stones of the arch has been laid by mixing white sand with beaten eggs to make it stronger and everlasting.

The Brari Bridge case study serves as a microcosm for the broader impact of handheld mobile terrestrial laser scanning on cultural heritage documentation. Nestled in a tapestry of history and engineering marvel, Brari Bridge stands as a testament to human ingenuity, but with the passage of time comes the imperative need for comprehensive documentation and preservation.

The bridge consists of a single semi-circular arch decorated by a band of squared stones. The technique used in its construction is based on the partial and simple processing of stones and in relation to lime mortar.

In terms of the architectural-functional treatment, depending on the line drawn by the level of the cobblestone, the Brari bridge is a bridge with a ridge or hump at the joint of the vault.

The bridge's foundations are the fundamental component that allowed the object to make touch with the earth; they are especially crucial to the stability of the structure. Therefore, the builders aimed to build the bridge on solid rock banks to avoid support failure, which would have increased strains in the arch and caused cracks, and to handle the huge horizontal and vertical loads produced by the arch of the bridge.

Depending on the height of the river mouth, the Brari bridge is classified as a single arch bridge, with the arch supported on rocky banks, where the footings were quite high above the level of the river bed.

This case study encapsulates the challenges and triumphs of applying cutting-edge technology to a historical structure, showcasing how handheld mobile terrestrial laser scanning can unlock the secrets of the past while ensuring the continuity of cultural legacy into the future.

As we delve into the intricacies of the Brari Bridge case study, this exploration will unravel the specific nuances and unique challenges posed by this cultural heritage site. From capturing the fine architectural details of the bridge to assessing its structural integrity, handheld mobile terrestrial laser scanning emerges as an invaluable ally in the documentation process. This case study not only highlights the technical capabilities of the technology but also underscores its role in preserving the authenticity and cultural significance of heritage sites.

2. Methodology

2.1. Handheld mobile terrestrial laser scanning

Handheld mobile terrestrial laser scanning is a cutting-edge technology that combines the precision of terrestrial laser scanning with the flexibility of handheld mobility. This innovative approach revolutionizes the way we document and analyze cultural heritage sites, archaeological landscapes, and structures of historical significance.

Terrestrial laser scanning itself involves the use of laser beams emitted from a stationary device to measure distances to surfaces, creating a detailed point cloud of the scanned area. The handheld mobile variation takes this technology a step further by incorporating portability into the process. This means that instead of being confined to stationary positions, practitioners can now carry the scanning device throughout a site, capturing intricate details with unprecedented flexibility.

The handheld mobile terrestrial laser scanner typically consists of a lightweight and portable device equipped with advanced laser scanning technology. It may include a combination of lasers, sensors, and cameras, all working together to capture highly accurate three-dimensional data of the surroundings. This handheld nature allows for dynamic scanning of spaces that were once challenging or impossible to document comprehensively, such as intricate architectural details, archaeological excavation sites, or other areas with limited accessibility.

The applications of handheld mobile terrestrial laser scanning are diverse. In the context of cultural heritage documentation, it enables researchers and preservationists to create detailed and accurate digital replicas of historical sites, artifacts, and structures. This technology is particularly valuable in archaeological excavations, architectural surveys, and conservation efforts, where capturing precise measurements and details is crucial.

The real-time data acquisition capability of handheld mobile terrestrial laser scanning provides immediate feedback to users, allowing them to adapt their scanning strategies on the fly. This adaptability proves beneficial in navigating complex and dynamic environments, ensuring that no details are overlooked during the scanning process.

While the technology presents numerous advantages, challenges such as data processing complexity, potential limitations in scanning range, and the need for skilled operators are aspects that should be considered.

Handheld Mobile Terrestrial Laser Scanning (HMTLS) brings versatility and mobility to 3D data capture, but it is not without its disadvantages. HMTLS devices often face limitations in range and accuracy compared to their larger, stationary counterparts, potentially compromising the quality of point cloud data. The field of view is typically narrower, necessitating more effort from operators to cover entire environments, leading to potential data gaps. Operator skill becomes a critical factor, as inexperienced users may struggle to maintain consistency in scanning techniques, introducing variations in data quality.

Handheld Mobile Terrestrial Laser Scanning (HMTLS) encounters distinct challenges when applied in areas with dense vegetation. The laser beams emitted by handheld devices may struggle to penetrate through the thick foliage, resulting in incomplete data capture beneath the canopy and generating gaps in the point cloud. The presence of leaves, branches, and other vegetation introduces noise and distortions into the scanned data, making post-processing more intricate and time-consuming. Identifying ground surfaces amid the vegetation becomes problematic, impacting the accuracy of elevation data. HMTLS may need to operate at reduced ranges and slower speeds in vegetated areas, prolonging the scanning process.

Moreover, wet surfaces due to rain or dew on vegetation can lead to additional reflections and refractions, further compromising the accuracy of laser scans. Navigating through dense vegetation poses physical challenges, risking damage to the handheld scanner and impeding its movement.

While HMTLS provides mobility, its limitations in vegetated environments necessitate careful consideration of its applicability in such settings.

Despite these drawbacks, HMTLS remains a valuable tool in scenarios where portability and flexibility outweigh the inherent limitations.

Nonetheless, handheld mobile terrestrial laser scanning stands as a powerful tool in the modern toolkit of cultural heritage professionals, offering a dynamic and efficient means of preserving and studying our shared history.

2.2. Data acquisition

2.2.1. Device setup

Vidoc RTK Rover was used to perform laser scanning of the Brari bridge.

Providing real-time kinematic (RTK) location to enhance the precision of the mapping results in comparison to the stock GNSS receiver included in the iPhone, the viDoc RTK Rover was a crucial part of the mapping process. The viDoc RTK Rover employs the RTK correction signals that the CORS stations continuously monitor from satellites to offer centimeter-level location accuracy. By connecting the viDoc RTK Rover to the iPhone 13 Pro Max using Bluetooth, the device was able to get real-time corrections and enhance the system's placement. LiDAR, or light detection and ranging, and a high-resolution camera on the iPhone 13 Pro Max were used to record depth information and take pictures, respectively.

The LiDAR sensor created a point cloud of the region, which gave us a complete 3D representation of the object space and allowed us to understand the road infrastructure, while the camera took pictures of the road infrastructure. The mapping procedure was made more accurate and efficient by using the Pix4Dcatch app for image processing and automated alignment between the photos and LiDAR data.

The data gathered by the RTK Rover and iPhone 13 Pro Max as shown in Figure 2 was processed using the Pix4Dcatch software to produce a 3D reconstruction of the road infrastructure. The application employed LiDAR and image alignment, as well as RTK data, to enhance the mapping findings' geolocation precision. The iPhone 13 Pro Max's ability to receive real-time adjustments from the RTK Rover through Bluetooth communication enhanced the mapping findings' accuracy even further.

Figure 2. ViDoc RTK rover (Pix4D).

2.2.2. Point cloud generation

Real-time data collection and analysis of the LIDAR point cloud data in the field was made possible by the pairing of the Pix4Dcatch app with the iPhone 13 Pro Max. The LiDAR sensor data was processed using the Pix4Dcatch software to create a point cloud. Data from the viDoc RTK rover obtained via the VRS network was also used to increase the mapping results' geolocation accuracy. A first representation of the point cloud was produced using the Pix4Dcatch app on the iPhone 13 Pro Max using LiDAR point cloud data; however, more image processing was needed to produce a high-resolution point cloud by giving additional camera sensor data.

After that, the information gathered by the iPhone 13 Pro Max was moved to a computer running thePix4Dmatic program to be processed further. By combining the LIDAR point cloud data with the picture collected by the iPhone 13 Pro Max, thePix4Dmatic software was able to produce a more precise and in-depth depiction of the road infrastructure. Additionally, the software used cutting-edge algorithms and computer vision techniques to increase the mapping results' accuracy.

In addition to RTK GNSS data, the Pix4Dmatic program included control points that were obtained through field-based georeferencing utilizing GNSS receivers. The places in the point cloud that were designated and clearly distinguishable by the user were referenced using this data. Pix4Dmatic's use of photogrammetric image processing made it possible to create a very precise and in-depth 3D model of the object space. To increase the accuracy of the mapping findings, the software automatically aligned the LIDAR point cloud and images data and employed the RTK GNSS and georeferencing data.

Figure 3. Point cloud generated in Pix4D Mapper.

3. Results

3.1. Accuracy assessment of Point Cloud

By comparing manually measured RTK-GNSS ground control points (GCPs) with digital elevation models (DEMs) generated from the point cloud data, the point cloud data's absolute accuracy was evaluated. To do comparisons, point clouds produced by mobile handheld terrestrial laser scanning require a common reference. In this case, we employed a standard digital elevation model (DEM) for assessment and opted for the inverse distance weighting (IDW) interpolation technique, which is commonly employed for interpolating data sets with irregular spacing, such point clouds. Equation 1, which can precisely compute the lowest grid resolution (p) depending on the data density, was used to find the ideal grid resolution for this investigation. For every dataset, different DEM surfaces were produced at different grid resolution calculations.

$$p = 0.5 * \sqrt{\frac{1}{D}} \quad (1)$$

where D is the average point density (number of point/dm2)

Every RTK-GNSS GCP (ZGCP) and the elevation of the point at the same position (ZDEM) in DEM were compared to determine the elevation difference. Additionally, using the vertical differences between the observed RTK-GNSS control points (ZGCP) and the points on the DEM surface at corresponding coordinates, the root mean square error (RMSE) and standard deviation (SD) were calculated. These points are dispersed over the research region and unrelated to the point cloud and DEM creation. This is how the RMSE and SD were computed:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Z_{GCP}(X_i{-}Y\mathrm{i}) - Z_{DEM}(X_i{-}Y\mathrm{i}))}{n}} \quad (2)$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(Z_{GCP}(X_i{-}Y\mathrm{i}) - Z_{DEM}(X_i{-}Y\mathrm{i}) - \mu)}{n-1}} \quad (3)$$

RTK-GNSS data that were manually measured were used to assess absolute accuracy. Table 1 provides the computed error statistics for DEM surfaces with regard to every ground control point. Every statistical number is below the centimeter threshold, as can be seen in the table. When the error statistics of the two systems were examined, it was found that there were not many differences in the point cloud data that came from each system. In addition, every point cloud data had notably high vertical accuracy, according to the results, and the datasets were satisfactorily georeferenced at the centimeter scale, making them appropriate for the purposes of this study.

Table 1. Error values of point cloud data

Min (m)	Max (m)	SD (m)	RMSE (m)
-0.07	0.015	0.025	0.045

4. Conclusions

The study's objective was to assess the precision of mapping the Brari bridge using an iPhone 13 Pro Max equipped with a viDoc RTK Rover. The point cloud data's absolute correctness was assessed using manual measurements obtained from a GNSS receiver.

With error values close to the centimeter level, the results show that the vertical accuracy of the iPhone-viDoc point cloud data was significantly higher. At the centimeter scale, the georeference of the dataset was done satisfactorily. This implies that a high degree of accuracy can be achieved for cross-slope evaluation and road border extraction using all three approaches.

By comparing manually measured RTK-GNSS ground control points (GCPs) with digital elevation models (DEMs) generated from the point cloud data, the point cloud data's absolute accuracy was evaluated.

The challenges posed by the vegetation's obstructive nature demand specialized techniques to clear the point cloud effectively while safeguarding the integrity of heritage structures. Integrating RGB or multispectral data within the HMTLS workflow can enhance vegetation clearance accuracy while maintaining the authenticity of heritage elements.

In summary, the study shows how an iPhone 13 Pro Max and the viDoc RTK Rover may be used to map road infrastructure and assess cross-slope conditions with great accuracy. The outcomes further demonstrate that, for these reasons, UAV-LiDAR data can be substituted with the iPhone-viDoc point cloud data. Future research could look into applying PPK on the viDoc RAW data to further enhance the tests and achieve even higher georeferencing accuracy.

The study offers insightful information about the application of mobile mapping tools for the assessment and mapping of heritage sites.

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