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Research paper

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Modelling a sacred object using MLS data and non-metric images

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Summary

Today, surveying technologies used in geodesy play a key role in the documentation and analysis of objects. The development of surveying techniques has been significantly influenced by improvements in hardware and software for data collection and processing. In addition to traditional methods such as surveying, photogrammetry and laser scanning techniques, which allow much more data to be collected in a relatively short period of time, are being developed at a remarkable rate. These techniques make it possible to create spatial models of objects, on the basis of which a more extensive analysis and the acquisition of technical documentation can be conducted. The study used a mobile laser scanning technique and non-metric images to acquire data to create a 3D model of a historic sacred building. The scanning was performed using a low-cost handheld mobile laser scanner (MLS) equipped with a Livox-Mid360 sensor from MandEye, based on SLAM technology derived from robotics, which was mounted on a bracket and stand made by Ronin. The images were taken using the camera of a Samsung Galaxy M51 mobile phone. The object of the study was the historic wooden church of St. Mark in Rodaki. The object was modelled in the Agisoft Metashape and Cyclon 3DR programs. The created models were compared by creating a differential model in CloudCompare software.

Keywords

MLS • non-metric images • 3D model

1. Introduction

The possibilities offered by surveying techniques today are not just limited to the creation of detailed, two-dimensional maps, but allow the development of 3D models of various architectural objects. Depending on the need, the scale of the surveyed object or the intended use of the final product, geodesy provides ready-to-use survey methods. For example, if one wishes to develop a detailed façade for the purpose of creating technical documentation, the most accurate method proves to be the laser scanning technology. This method makes it possible to collect information about shape and dimensions in the form of a point cloud in a very short time, with extreme accuracy, where the error often does not exceed 5 millimetres. However, there are situations where the constraints of the terrain layout or the structure of the object do not allow the acquisition of full information about its shape. In such situations, the solution is to integrate data from different surveying instruments [Kwoczyńska and Małysa 2022].

Among the commonly used tools for data acquisition are Unmanned Aerial Vehicles (UAVs), which are becoming increasingly popular, ubiquitous and widely used [Salandra et al. 2023, Pádua et al. 2022, Stal et al. 2022]. However, spatial object data can also be obtained in many other ways, among them aerial [Kwoczyńska 2019] and terrestrial [Boroń et al. 2007] photogrammetry as well as terrestrial and mobile laser scanning [Michałowska et al. 2015, Kędzierski et al. 2008, Kwoczyńska et al. 2016, Rizzi et al. 2011]. Due to its versatility and effectiveness, MLS (Mobile Laser Scanning) is a valuable tool for collecting data. It generates a point cloud that is then used to create detailed models of urban environments, assess infrastructure and support natural resource management using additional information such as remote sensing or dendrology. Over the years, advancements in sensor technology and data processing capabilities have significantly improved the resolution and accuracy of data collected by MLS systems [Puente et al. 2013].

The use of non-metric cameras to record architectural objects and the possibilities that specialised photogrammetric software now offers have also popularised this method of data acquisition for developing 3D models of architectural objects. Terrestrial images currently used for photogrammetric measurements are taken with various types of digital reflex cameras. The documentation created on their basis is characterised by a high degree of detail and high accuracy of representation.

The photogrammetric method is a very complex process, involving many technically and computationally demanding procedures. However, if the aim of modelling is to achieve the best geometric accuracy, metricity and detail, this method is indispensable. Contemporary architectural inventory and building description, as well as the cataloguing of historic buildings, are based on this method [Kwoczyńska 2019].

The aim of the study was to present the possibility of using non-metric images and data acquired with mobile laser scanning to produce a 3D model of a sacred object. The location of the object and, above all, its inaccessibility gave the opportunity to test the appropriate data acquisition tools in order to obtain the best possible 3D model of the object under study.

The study centred on comparing the accuracy, density and completeness of the point clouds generated by the two techniques, in the context of object modelling.

The point clouds created made it possible to produce 3D models. These, in turn, were used for analysis in terms of both the obtained accuracy and detail. The results of the study indicated the benefits and limitations of each method, which is important for the fields employing the chosen data acquisition technologies, and suggested optimal applications depending on project objectives and available resources.

2. Characteristics of the study object

The study object was the St. Mark's Roman Catholic Church in Rodaki (Fig. 1), located about 17 km from Olkusz, in the Małopolskie Voivodeship. It is a historic building, located on the Trail of the Eagles' Nests in Jura Krakowsko-Częstochowska. It was built in 1601, and it is a detached log structure oriented in such a way that its walls face north, south, east and west. It has no distinct stylistic features [Walusiński 2017]. The church has a single nave, with a vestry on the north side of the chancel. The roof of the church has a steep and multi-pitched construction with a single ridge and has been covered with shingles. At the top of the roof is a wooden bell turret in Baroque style. The interior of the church is characterised by flat ceilings and a semicircular rainbow, which features a Baroque crucifix [https://zabytek.pl/].

Source: https://www.zabytkitechniki.pl/culturalheritage/322247/modrzewiowy-kosciol-sw-marka-w-rodakach

Fig. 1. St. Mark's Church in Rodaki

The church was entered on the list of wooden historic buildings in 2001 and was included in the Małopolska Trail of Wooden Architecture. It is called the Wooden Pearl of Jura.

The area around the church is fenced off and overgrown on three sides with old trees, making the site difficult to access for surveying.

3. Surveying methods

Data for object modelling were acquired using two independent methods. Photographs were taken using a camera from a Samsung mobile phone, model Galaxy M51 (Fig. 2), and mobile laser scanning was performed using a MandEye LIVOX MID-360 laser scanner (Fig. 3).

Source: Authors' own study

Fig. 2. Samsung Galaxy M51 camera

Source: Authors' own study

Fig. 3. MandEye LIVOX MID-360 mobile laser scanner

3.1. Mobile laser scanner (MLS)

MLS (Mobile Laser Scanning) is a technology using the LiDAR (Light Detection and Ranging) technique to acquire 3D data. It is a very efficient technique due to the rapid collection of large amounts of data in a short period of time. MLS combines LiDAR sensors with GNSS global navigation systems for data georeferencing and IMU (Inertial Measurement Unit) to create precise 3D point clouds of the scanned object. MLS often integrates camera sensors, allowing video recording and providing colour information of the individual elements included in the point cloud by assigning an RGB value to each point [Lu and Zhou 2010].

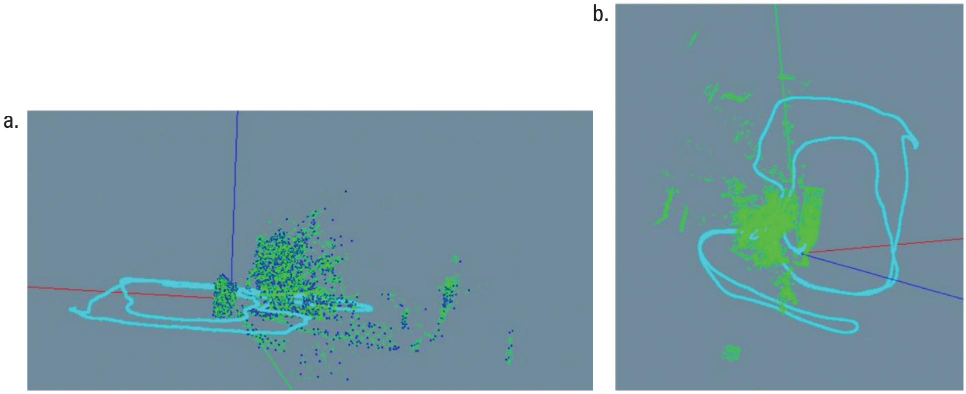
The mobile laser scanner is capable of capturing millions of 3D points. The measurements of X, Y, Z coordinates can be imported into specific CAD software as point clouds of which colour features can be changed. Point cloud files can be viewed, navigated, measured and analysed as 3D models [Puente et al. 2013].

Mobile scanners placed on various types of mounts and backpacks are used to survey objects that are difficult to access. An example of such a solution is the LIVOX MID-360 mobile laser scanner, which has an approximate scanning range of up to 40 m, a measurement precision range of ≤ 2cm/10m. The speed at which the device operates allows the acquisition of 200,000 points/sec.

The survey of the church in Rodaki was carried out with the LIVOX MID-360 laser scanner by MandEye, which was mounted on a bracket and stand made by Ronin.

The capabilities of the instrument allow it to obtain a point cloud of elements within a range of up to 40 m. The area of points it captures is within a horizontal range of 360° and a vertical range of up to 59°. The instrument weighs less than 1 kg and the battery provides approximately 5 hours of operation.

Before the measurement was taken, a walking route was planned with the LiDAR instrument so that the scanner could reach each element of the site (Fig. 4a and b). The instrument was then set up on a stand, at the starting point of the measurement, so that it would be possible to finish the measurement in the same place.

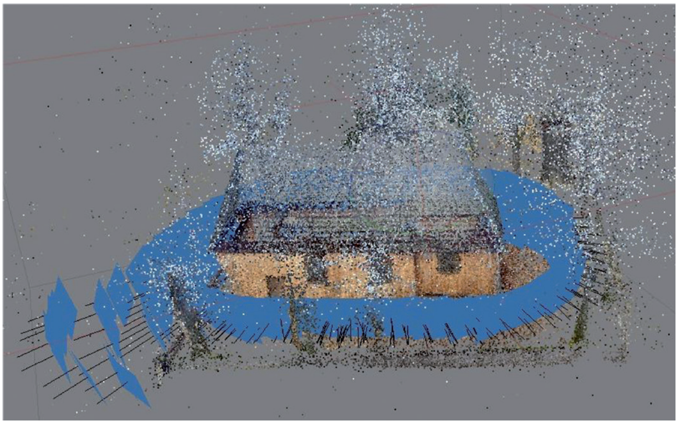


Source: Authors' own study

Fig. 4. Visual representation of the path of the completed measurement of: a. side and b. top view

3.2. Non-metric images

The photos were taken with the main camera, which has a resolution of 64.0 MP, F1.8 brightness, with flash off and white balance. The display resolution was 1080 × 2400, with a colour depth of 16M. The 7,000 mAh battery, meanwhile, allowed for independence of operating time. The technical parameters of the device ensured optimal image quality by enabling the acquisition of a point cloud.



Source: Authors' own study

Fig. 5. An indication of the camera's position during image capture using a sparse point cloud as an example

Photo: S. Olszańska

Fig. 6. Targets used on the north-east side

Before the images were taken (Fig. 5), 12 targets (Fig. 6) were placed on the study object itself to facilitate the generation of the point cloud and to acquire distances to scale the cloud. The targets were placed as evenly as possible considering the field conditions [Olszańska 2024].

In order to obtain sufficient data, 240 photographs were taken from three elevation levels. Due to terrain difficulties, such as heavily branched, massive trees overshadowing the site, difficulties with access from the west side through the fence, some of the photographs were taken only as the terrain conditions allowed.

4. Study results

4.1. Modelling based on non-metric images

Agisoft Metashape Professional software was used to generate a point cloud from the acquired 240 images. The development required measurements on the placed targets and other landmarks. The measured distances between them were entered in order to scale the cloud. Once sufficient accuracy was achieved, which was 0.01 m, a dense point cloud was produced. This cloud was cleaned of measurement noise (Fig. 7) and could, at a further stage of the work, be used to generate a 3D mesh model.

Source: Authors' own study

Fig. 7. Cleaned dense point cloud in Agisoft Metashape

The resulting 3D mesh model of the church (Figs. 8 and 9) has a high level of detail thanks to the large number of photographs used and the accuracy of the model.

4.2. Modelling based on MLS data

The lidar_odometry software was used to process the spatial data obtained from the mobile scanning.

As a result of the processing, a report was produced indicating, among other things, the total number of points, the covered distance and the time taken to complete each

Source: Authors' own study

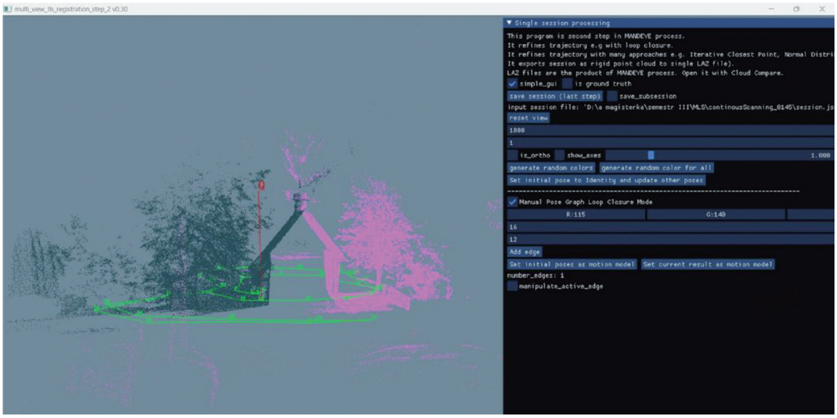
Fig. 8. A 3D mesh model of the north-west wall view

Source: Authors' own study

Fig. 9. A 3D mesh model of the south wall view

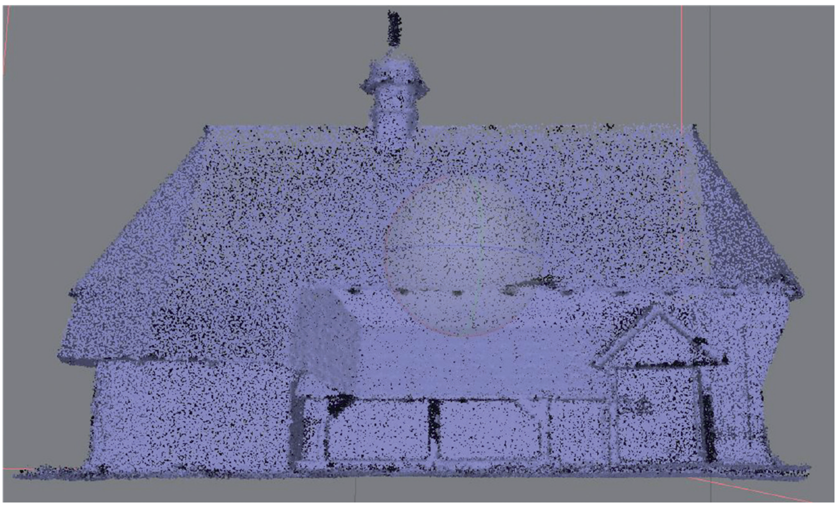
separate area shown individually and as a whole. In the area of the measurement range, smaller point clouds were extracted. The report indicated a distance travelled of 197.722 m in 221.925 seconds. During this time, 41 point clouds were indicated. One of the data processing stages led to the refinement of the measured trajectory using, among other things, inertial point clouds and normal distributions transformation (NDT).

The software offers the possibility to manually adjust the position of point clouds in relation to each other. At the same time, it also allows modification of the displayed view, making it possible to change the colours or density of the displayed cloud (Fig. 10).



Source: Authors' own study

Fig. 10. Comparison of the link between two point clouds

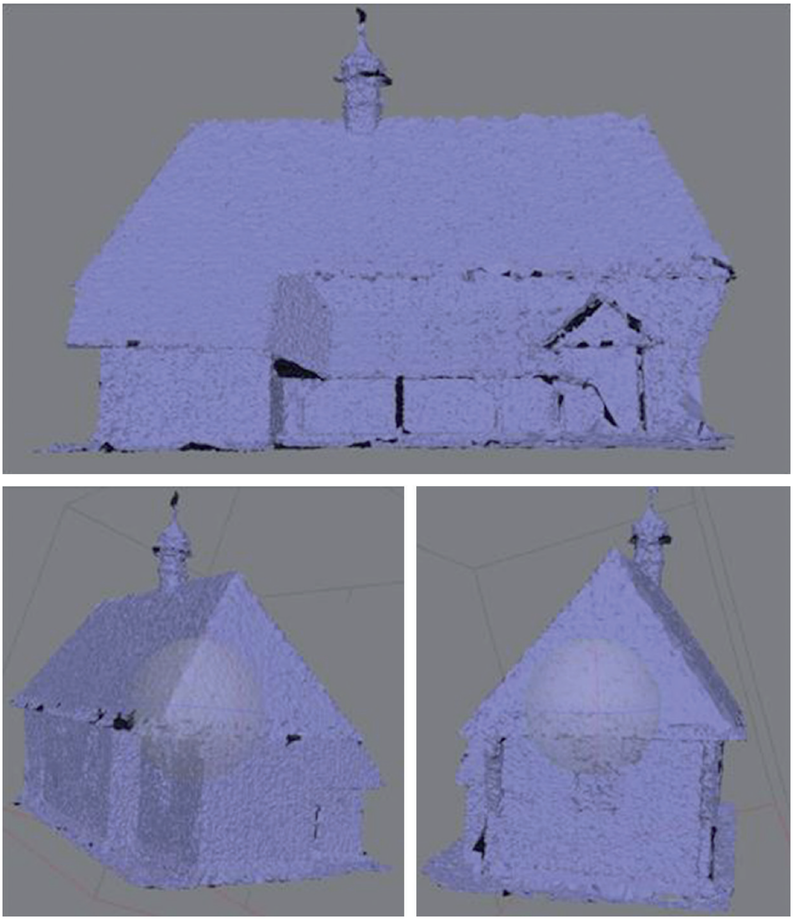


Source: Authors' own study

Fig. 11. Cropped extent of the point cloud in the south-east wall view

After performing the necessary steps to align the point cloud, an aggregate LAZ file was generated. The cloud was then cleaned of measurement noise, and the result can be seen in Figure 11. In this case, the cloud does not contain RGB colours, as only a scan was taken, with no additional images of the object.

The generation of the 3D model from the MLS point cloud was initially performed in Agisoft Metashape, but due to unsatisfactory results, the model was finally created in Cyclone 3DR (Fig. 12). Regular sampling parameters were selected for the generated model in order to obtain a regular grid distribution from the point cloud. The average distance between points was set at 0.15 m (chosen for the best aesthetic value of the model), and the Hole detection function was used to fill gaps in the mesh, if any appeared.



Source: Authors' own study

Fig. 12. Result of the modelling carried out in Cyclone 3DR – north wall, south-east and north wall

5. Conclusions and results

Data acquisition for the chosen study object, due to its nature, as well as its location and accessibility, required the selection of appropriate survey techniques. It was not possible to use BSP due to the proximity of tall trees on each side of the object, nor ALS data (Airborne Laser Scanning), which only provided information about the roof of the object.

The use of a non-metric camera for shooting proved to be the most suitable in this case, mainly because the camera could be moved freely during shooting. This helped considerably with obstacles such as trees, fences and an embankment.

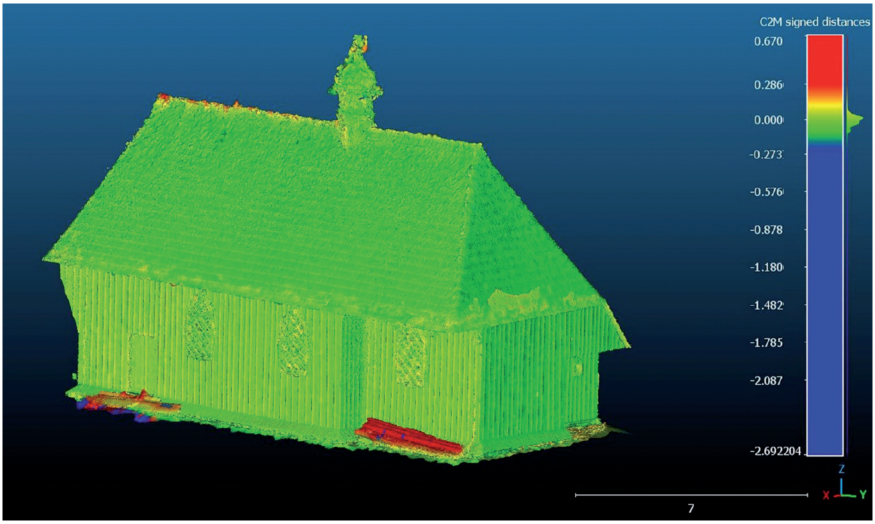
Mobile laser scanning also proved to be an effective method of data collection thanks to its ability to access any part of the object in this situation. This flexibility was largely achieved by operating the scanner manually using a handheld holder.

The point clouds acquired by both techniques have comparable completeness – they have well-captured details and elements. However, they differ significantly in density, as the cloud from the images is more than 76 times denser than the cloud acquired with the mobile laser scanner.

From the point of view of the accuracy of the execution of the model and working on the acquired data, the model created from the photographs gave very positive results. Reason for this were the correctly taken photographs, the low error involved in entering distances for rescaling and the capabilities of the software to produce a realistic model.

Meanwhile, the model created from the mobile laser scanning data provided interesting insights. The acquired point cloud came out visually and geometrically correct. On the other hand, using the same parameters of the modelling algorithm in Agisoft Metashape as in the case of the model from non-metric images did not quite give the desired result. When the point cloud was carefully cleared of measurement noise, the model generated additional elements at the edges of the roof, at the turret, at the vertical beams, among others, which resulted in a somewhat deformed model. An attempt to generate the model using other parameters only showed the effect of the interpolation algorithm on the model generation. However, the result of the generated model may have been influenced by the point cloud density. The number of points acquired for the object under study using the MLS was 498882 points, while by comparison the generated cloud from photographs had 38049503 points. Despite this, the same number of points did not result in distortion in the Cyclone 3DR. This, in turn, may have been influenced by the more customised settings for such data characteristics, i.e. the scanned point cloud. The exact differences between the automatically created 3D models are shown by the differential model (Fig. 13), which was prepared in CloudCompare.

Larger differences in distance were designated at unstable wooden elements leaning against the walls of the object. These include various types of planks highlighted in red and blue. It is likely that this difference is due to the possibility of these objects being dislocated by weather and environmental factors. This was largely influenced by the time gap between the mobile laser scanner measurement and the taking of the photographs.



Source: Authors' own study

Fig. 13. Differential model

In general, the values for the differences in distance between the created models that were noted in the histogram are in the range of 0.45 m to –0.37 m. The range of these values may have been a consequence of differences in the visual presentation of the models, the accuracy of their fitting and the used method of scaling the point cloud. The visible differences at the edge of the roof and on the turret are caused, in part, by measurement noise (especially on the image-generated cloud), which resulted from the difference in roof height relative to camera height.

The study, which focused on the use for 3D modelling of a widely available digital camera in a mobile phone and a low-budget handheld mobile laser scanner (MLS) equipped with a Livox-Mid360 sensor, based on SLAM technology originating from robotics, just entering the surveying market, led to the following conclusions:

- The use of images taken with non-metric cameras, even those in very good mobile cameras, enables the generation of a point cloud that can be the basis for an accurate 3D model of a complex and historic architectural object.
- The use of a low-budget mobile laser scanner allowed the rapid acquisition of data on an object that is difficult to access; the quality of the data does not differ at all from that obtained from terrestrial images.
- A 3D mesh model made from a point cloud from mobile laser scanning, based on SLAM technology originating from robotics, differs little in terms of geometry and detail from that obtained from photographs.
- A shortcoming of the 3D mesh model derived from the data acquired with this particular mobile laser scanner is the lack of original textures of the object, resulting from the inability to simultaneously take images and measurement.

- Agisoft Metashape performed much better in creating a 3D model from a point cloud extracted from photographs than from the MLS point cloud, which required the use of Cyclone 3DR – a software with a wider range of possibilities in the selection of modelling parameters.

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