Texturised 3D models using photo scanning

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The authors describe a remarkable system for the capture in high resolution of objects in 3D. Based on digital cameras and software, the technique can serve as a useful complement to existing laser scanning.

Nowadays, the documentation of an artefact through 3D modelling techniques implies reliance on the latest technologies dedicated to cultural heritage. Until recently, laser scanning has been seen as the most effective and innovative solution but now there is a new approach. Photo scanning uses imagery as a single information source, in order to obtain metrically valuable and widely extensive exploitable data directly from the chromatic features of the artefact itself.

The photo scanning approach has been developed and set up by Menci Software over two years, and has led to the design of several tools addressed to help the user in the survey and 3D modelling fields. The Z-Scan class of instruments, to which all of these tools refer, covers different application domains, dependent upon whether the application is the subject of study or the operating context. One of these domains is cultural heritage.

Z-Scan technology provides the generation of point clouds through the exploitation of the imagery obtained by the use of common and professional digital cameras. The shooting system depends upon a particular camera and lens calibration technique that has been developed by Menci Software, and on a precision slide bar with forced-centering and default positions. The analysis technique and the software for the point cloud generation is supported by an innovative multi-focal image analysis algorithm, that provides high accuracy in terms of geometry and chromaticity.

The handiness of the system, the robustness of the components and the reliability of the results, make Z-Scan technology a perfect complement for use in fields such as cultural heritage and in wider application areas that focus on the preservation of architectural, monumental and archaeological heritage, as well as in the museum field.

The system allows the creation of a 3D copy of the object through an indirect metric survey, which is carried out without "touching" the object and does not require photogrammetric control points. There is no need for any additional instrument to complete the survey: Z-Scan is completely autonomous. From image acquisition to the measuring phase, the system is totally supported by software developed in Italy.

The system was initially designed for non-expert users operating in the cultural heritage sector, but soon it gained visibility in several other fields.

From pixels to coordinates: reversing the 3D modelling paradigm

Z-Scan, which can also be used for documentation purposes, is designed to measure an artefact through imagery in order to better understand the object in three dimensions. The support of imagery makes the system particularly suitable for surveys in the cultural heritage field where the chromatic informative component is often decisive in comprehending degrade phenomena or for assisting in interpretation, techniques of hand working or dating issues.

The result of a survey conducted with the Z-Scan is a high-resolution 3D point grid that, together with the texture component of the image, represents a 3D raster documentation of the surveyed artefact. On this digital object, it is possible to carry out measurements, produce graphical thematic classification of the model, create hyperlinks to information collected in geo-databases, connect stratigraphic information within the excavation record, define 3D representations in CAD and GIS environments and also generate high performance ortho-images and photo-mosaics.

The real benefit brought by the photo scanning approach refers directly to methodological issues. The Z-Scan system allows one to reverse the survey paradigm that defines the current use of laser scanning, especially when surveying historical artefacts. The traditional 3D modelling of texture has always been seen as connected with the flux of data generated by a laser scanner; this flux of created data is based on a geospatial grid of single points that pertain to the final point cloud. A laser scanned 3D point cloud does not contain information about the space between neighbouring points. It also relies on a second data source – a camera – to assign RGB values to each point in the cloud. In order to obtain accurate ortho-images, it is then necessary to georeference images or portions of a single image, and apply them to the model following the reference points.

Z-Scan uses a single data source, the photographs, and reverses the above

Some 3D models created with Z-Scan

Some Z-Scan systems for acquisitions in different application environments: a standard system, a micro system and a rotating plate.

mentioned process: the single geospatial point information is generated directly from the image pixels that represent the actual object, creating a bidirectional relationship that allows the production of extremely accurate and reliable models.

In these conditions, a unique texture representation of the surveyed 3D model is possible. The object is represented as a mesh of elements, typically of resolution five to ten pixels, in which every single face in the model depicts the original chromatic elements acquired by the digital camera, and not just the interpolation typical of laser scanner RGB points or those encountered when dealing with the generation of ortho-images on the basis of interpolated DTMs. Therefore, taking a single georeferenced point on the final 3D model of the artefact, it is possible to spot the actual correspondence between the photo scanned model and the real object. This would be impossible using laser scanned data, even if dealing with high quality images.

"Photo scanning uses imagery as a single information source. . ."

It is also worth considering the continuity and contiguity of the chromatic information. These features are impossible to guarantee with laser scanner systems because the result of a point cloud is, by definition, made up of small standalone elements. A digital picture instead depicts an object by its pixels. One of the main trademarks of pixels is the proximity with other similar elements, the totality of which is the representation of the entire image.

The objective of this argument is not to downgrade laser scanner technology as somehow inadequate for the accuracy purposes of a survey. In the case of very widespread surfaces, it is still necessary to rely on a topographic or laser scanner survey, especially in order to gain a good zero order reference frame. Explained in this way, Menci Software's innovative solution based on photo scanning, clearly integrates with other techniques.

Z-Scan system: technical details

Z-Scan solutions operates between acquisition ranges which can vary from a few centimetres to ten metres; this consequently affects the accuracy of the models which are themselves affected by several variables like the quality and resolution of the lenses being used or the distance and the lighting of the subject of the survey.

The photo scanning approach is entirely based on images, their production is extremely important and functional to a correct development of the work; it is also useful to consider that, in the presence of surfaces with consistent chromatic values it would be necessary to use a system with pattern projection. Photo-scanning systems have proved their capabilities on the different chromaticity of close pixels, and this condition is essential to succeed in the work. Solutions based on Z-Scan are easy-to-use, light weight, simple photogrammetric systems. The system is perfectly suited for the needs of non-expert users, allowing them to create 3D models with just three digital camera shots (without any further intervention) as it is not necessary to have any control point or preliminary measurements.

Recently, Menci Software's R&D department put a lot of effort into simplifying the post-processing phase of the system. This led to a totally automated solution capable of joining multiple Z-Scan point clouds by registration of overlapping data using only the photographic texture. It is however possible to make use of control points, if available, to both ease up model registration and allocate them within the general reference system of the project.

Utilising various 2D-3D creation modes it is possible to generate orthoimages and web-based VRML models, or simply to digitize surfaces related to complex 3D models.

The operating tools

Z-Scan systems require data obtained using a suitably calibrated digital camera and a dedicated slide bar with length that can be changed to suit the type of survey or the dimensions of the artefact. Sometimes, it is possible to take a succession of images of a small object on a rotating plate that is interactively managed by the acquisition software.

The operating range of the instrument is variable based on the lens used. The default configuration generally relies on a Nikon or Canon camera, even though the user may choose different cameras. The accuracy of the image is directly linked to the acquisition distance and to the type of lenses used, whereas the camera can mount more than one calibrated optic, depending on the kind of survey carried out.

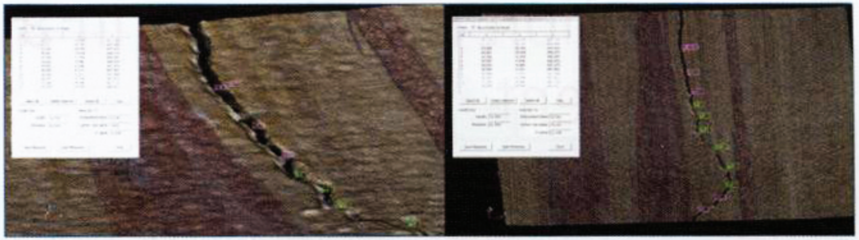
The camera must be set on a ball rail runner precision sledge (length 500-900mm) with tilt head, to guarantee the accuracy of the "shoot base". These data acquisition devices are fully supported by the Z-Scan point cloud generation software.

3D model generation

Post processing begins with the introduction of values concerned with image distortion. These values are collected during the calibration phase carried out in Menci Software's labs and are essential to avoid lens distortion.

Images are analysed by an operator in order to find a number of dependent features according to dimensions. The features' displacement affects the following calculation phase. It is necessary that all the features are distributed on all the photograms and that it is homogeneously texturised. An algorithm for the analysis and the filtering of the equivalent features based on epipolar geometry leads to the restitution of the orientation of the three photograms. The angular values of the shot trim are close to zero and their size depends on the building tolerance of the sledge, on the position of the camera on the rail runner, on the oscillation of the bar and, eventually, of the structure supporting it. Correct orientation is a fundamental prerequisite to guarantee the success of the photo scanning process.

Once the orientation is known, it is possible to proceed to trinocular rectification using data from the three camera images, aimed at the simultaneous removal of the vertical parallax on the three photograms.
Rectification is particularly complex because of the shot condition: close to perfect alignment, it represents an anomaly for the trifocal tensor. For this reason a specific trinocular rectification algorithm not dependant on trifocal tensor has been set up. Surface reconstruction takes place through image matching, using dynamic programming methods. Cross-correlation calculation is simultaneous on the three images and takes advantage of the RGB chromatic components.



3D detail of a fresco aimed to measure the size of a crack.

Conclusions

The 3D documentation methodology based on the Z-Scan system and on the photo scanning approach, represents a valid complement to work usually carried out using laser scanners. Moreover, it is the perfect system solution when the laser scanner approach is not applicable (for example if there are space problems or due to the size of the object to be surveyed). Z-Scan is a multifunction system, as it can work with the same hardware but with different focal lenses, making it possible to survey objects directly on site, in museums (e.g. capitals, columns, decorations and bas-reliefs) or in external areas.

> *“The object is represented as a mesh of elements. . .”*

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