“Low cost” techniques for building surveying and their 3D representation

A. Chiorboli, M. Gatti

Abstract—The fast improvement and the latest years cost decrease of digital cameras allow the use of photogrammetric solutions for 3D modelling, even in not specialized companies. Besides that, some cheap software solutions are available on the market. This article deals of two different solutions. The first one requires only some photographs, which elaboration is based on a cadastral map. The second one needs a stereopair and some distance measurements. The 3D modelling is done using a low-cost and user-friendly software.

Index Terms—3D, Close range, Low cost, Representation , Surveying.

I. INTRODUCTION

The italian reality of civil engineering and architecture companies is often characterized by small and medium-sized entities, that attend several aspects of their professional activities at the same time.

All that entails a low specialization and a limited investment power into each of their fields, to which is added a more and more specific intervention request on the existing building heritage (buildings, monuments, roads, urban parks, ...).

Starting from this preamble, it has appeared to us so interesting to realize and to test some surveying and building 3D representation methods, sufficiently accurate, of low-cost and with easy applicability even for little skilled users.

The methods, based on the terrestrial photogrammetry, use consumer digital cameras, on a telescopic tripod, and tools for the direct distance measure (handheld laser EDM, tapes, etc.).

The first test has been developed on a building estate area in Ferrara with one road and a monumental square. On the main road, there are buildings of urbanistic and historic importance. The survey was limited to the photogrammetric portion only, without a first order network.

Thanks to a support of a digital map, it was possible to scale the rectified photos and to make a 3D model, in a multimedia environment. The surveyed object representation was done with “consumer” software.

A second test has been made on a monument of historic and artistic worth, with a particular shape and geometry. In this last case, besides of photos, even photogrammetric support measures have been scheduled. The photogrammetric elaboration and the 3D object representation have been made with a low-cost photogrammetric software, on the AutoCAD environment. The model, obtained from the test has been compared, to measure the accuracy, with the real one. Finally, work times and realization costs have been valued for both tests and they are compared with these originated from the application of more professional photogrammetric methods.

II. THE AREA OF THE TESTS

The first test was carried out in a urban area of Ferrara, build during first years of the 20th century: the Rione Giardino neighbourhood. Building and demolition activities succeeded several times, so many past symbols and testimonies were destroyed. The present plan, called Fascist Addition, has the XXIV Maggio piazza as the core of the area. In the middle of the piazza there is the Acquedotto (water reservoir), which completes the perspective axis through Vittorio Veneto avenue (Fig. 1).

Fig. 1. A present sight of XXIV Maggio piazza, with the axis of Vittorio Veneto avenue.

A. Chiorboli is with the Dipartimento di Ingegneria, Università di Ferrara, 44100 Ferrara, Italy, www.unife.it (phone: +39-0532-974800; fax: +39-0532-974870; e-mail: achiorboli@ing.unife.it).

M. Gatti is with the Dipartimento di Ingegneria, Università di Ferrara, 44100 Ferrara, Italy, www.unife.it (e-mail: mgatti@ing.unife.it).
III. THE FIRST METHOD

A first test has been carried out on the whole Vittorio
Veneto avenue, as far as the XXIV Maggio piazza and the
result is a 3D photo-realistic model, in a multimedia
environment [1].

For the photogrammetric surveying of buildings it was used
a Canon IXUS430 amateur digital camera, with a CCD sensor
of 1/8", resolution of 4.1 Mpxels, lens 7.4-22.2 mm
(equivalent to a 36-108 mm on the 35mm format), making
JPEG format files over a Compact Flash card. The bi-
dimensional representation was executed on a cadastral map in
a raster format, at the 1:1000 scale, subsequently transformed
in a vectorial file in a AutoCAD environment. Then, the map
was scaled, using as a datum line a side of a building measured
directly from the cadastral map.

The vectorial map, obtained in that way, served for:
♦ to determine the dimensions, on the plan, of buildings
(those dimensions will allow to “scale” the rectified
images of the elevations);
♦ to rebuild the perspective sight of the avenue, with all
buildings on the sides.

The rectification of the digital images was done through a
fast method which consists into drawing in the photo a grid,
then to use that such as reference for the rectification [2]. This
method allowed to keep the images with a roughly proportion,
without the need of control points. A generic imaging software
allowed to correct the perspective deformations, getting the
elevation dimensions with a minimum error. Starting from the
cadastral map file, the solid building shapes has been created,
getting the three dimensions of each building, up to the tile
level.

Two are the 3D models obtained: the first one, in an
AutoCAD environment, allowed to determine the tile level and
some characteristic dimensions of some buildings, choosed
such as sample. Tile levels was used to make the second 3D
model, whereas the vectorialization (on the sides of building
3D models) of some architectural details allowed to carry out
a reliability test of the used rectification methods. The second
one, made with the SketchUp software, is built with the idea
that it can be used for the visualization, in real time and
through different points of view, of the urbanistic composition
of the avenue. On the last one, the rectified images has been
inserted.

The model has been rendered realistic thanks to the use of
detail components, such as trees, flower-beds and the insertion
of lights, which position is determined with the geographic
latitude and the day of the year when the user wants to see the
3D model. The main feature in that representation (Fig.2) is

![Fig. 2. Some images of the 3D realistic model [1].](image-url)
the possibility of to have, in real time, metrical data from the
3D represented model.

IV. THE SECOND METHOD

In the second test, we took into consideration the surveying of
a Southern elevation portion of the monumental building
called Acquedotto, through a low-cost photogrammetric
method, called Fotogram. Fotogram is a AutoCAD plug-in,
which allows to use all the management tools of images and
3D representation of the main software. It is suitable for either
not professional users or for users not expert in the
photogrammetric techniques [3].

The experimented photogrammetric system requires a
stereopair, that means two photos with perpendicular viewing
directions, made with the same camera settings. Pictures can
be done with any amateur camera, preferably digital camera.

To proceed with the surveying, the measures are the follow:
♦ The measure between the two points where the camera is
installed to do the stereopair. This segment is called base.
♦ From 1 to 4 lengths of the calibration segments, defined
between the control points. Those segments have to be
parallel to the base.
♦ The measure of the distance between each calibration
segment to the base.
♦ The relative position of the right extreme of the first
calibration segment, taken from the left point of the base.
This value, not always necessary, is called Xₐ.

In the Fig. 3 there is a schematic plan of the survey
operations, needed for the Fotogram elaboration.

Once the segment measurement values have been inserted
and the segment calibration extremes have been selected in
both images, the software suggests four elaboration options.
For each one, there will be a final report, where each cartesian
direction has an estimated error value. The operator will choose
the best elaboration option to minimize the errors presented in
the final report. When the Xₐ measure is available, Fotogram
can compute even the image rotation around the viewing
camera direction.

![Fig. 3 Schematic representation of a Fotogram survey.](image)

A. The instruments

Last generation digital cameras are suitable for medium
accuracy photogrammetric purposes, with satisfactory results
[4], [5], [6]. Even for that reason, for the second test, we used
a Nikon D70 reflex digital camera with a sensor resolution of 6
Mpixels. We did not calibrate it, since Fotogram does not
require the calibration constants.

The Nikon D70 CCD size is 23.7 x 15.6 mm, lower rather
than a traditional camera (36 x 24 mm) [7]. According to that,
the focal length of the Nikon D70 is about 1.5 times of the 36
x 24 camera (Table 1).

For the realization of the stereopair, the digital camera was
installed on tripods of surveying instruments. On each tripod,
there were a tribrach with a spherical spirit level. A teflon
connector allowed to screw the digital camera on the 5/8”
tribrach support (Fig. 4). The use of a toric spirit level,
inserted on the flash support on the top of the digital camera,
allowed to keep horizontal the camera body.

In conclusion, to avoid the possibility of slight movements,
the photo commands were given through an infrared Nikon
remote control.

We printed some targets (Fig. 5), on a thick paper of the A4
format. The same targets were used both for to put on the
surveyed object the control points and to locate some other
points that were necessary to verify the accuracy of the
photogrammetric system.

For the photogrammetric elaboration of images, the system
needs the use of very simple measurement tools, such as a tape
measure.

| TABLE I |
| 35 MM AND NIKON D70 FOCAL LENGTH |
| Focal length |
| 35 mm camera | 17 | 20 | 24 | 28 | 35 | 50 |
| Nikon D70 | 25.5 | 30 | 36 | 42 | 52.5 | 75 |
However, in this case we used a Topcon GPT 2005 reflectorless total station, with the purpose of to evaluate the accuracy of the whole method.

B. The measurement activities

To obtain the best results, it is necessary that:

♦ The calibration segments must be parallel to the base.
♦ The calibration segments and the base must be horizontal.
♦ The viewing directions of both images must be parallel.

However, the software can correct slight image rotations about the main axis. The perfect-rate base dimension depends from the focal length; a indicative ratio is 1/10 of the maximum distance between the objects and the camera.

Taking advantage of the presence of the total station, we prepared a simple Excel sheet, inserted in a laptop carried in the field during the surveying operations. The sheet was done on the base of geometric requirements, said just before, for the proper use of Fotogram.

The surveying operations were the follows:

♦ Location, on the real object elevation, of the first calibration segment through the application of two targets.
♦ Setting up of the total station and execution of linear and angle measurements on the two extremes of the first calibration segment; the perpendicular to this segment, passing through the middle point, is the symmetric axis of the surveying.
♦ Location of other targets, with a arbitrary position; these targets are the first origins of the following calibration segments. Execution of linear and angle measurements on these points.
♦ Introduction of angle and linear distances in the Excel sheet and coordinates computation of second extremes of calibration segments.

♦ Location, on the object, of the second extremes of calibration segments, using the tracking function of the Topcon total station;
♦ Materialization on the object of the second extremes of calibration segments through the targets and materialization of the base.

About the photogrammetric exposures, following settings were used:

♦ The lowest light sensitivity value (ISO 200).
♦ Aperture priority setting.
♦ High sharpening of the image.
♦ JPEG Image file with a resolution of 3008 x 2000.

Eight control points and the two base points have been surveyed, to define the four calibration segments and the base. We even measured the position of 12 more targets, with the aim of verify the accuracy of the 3D model made with

![Fig. 5 The shape of the target makes easy the centre location singling out. In particular, the central cross, in the center of the smallest circle, allows a easy and fast center location recognition with the use of a theodolite. The aim of the big cross is to make easier the recognition of the target center during the photogrammetric elaboration, as it is showed in the central and left images.](image)

![Fig. 6 An image of the photogrammetric and surveying operations.](image)
TABLE II

RESULTS OF THE PHOTOMETER ELABORATIONS

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Rotations

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Estimated errors

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Fotogram.

C. The 3D modelling

The 3D modelling was done with AutoCAD using the Fotogram plug-in. The operator must choose on manual the positions of the control points and insert some parameters: the calibration segment lengths, the distance between the base and the calibration segments, the measure of the base, the X_A coordinate (Fig.3). Finally, we proceeded with the elaboration using all four options: high deformation, medium, low, and no deformation (Table II). We chose the medium deformation solution, because it has the lowest estimated errors.

D. Accuracies

The Cartesian reference system used by Fotogram has the origin in the center of the left photo, the XY plane coincides with the plane of the left exposure; in particular the X axis joins the left exposure center with the right one. The Z axis is perpendicular to the picture plane. In this reference system we compared the two different coordinate sets obtained from the whole procedure: the first one made with the 3D coordinates given by Fotogram and the second obtained with the total station surveying. So, the result is a matrix of 36 3D coordinates for each method. With this sample, we obtained the differences, ΔX, ΔY, and ΔZ, the difference averages ΔX_med, ΔY_med, and ΔZ_med, their variances σ_ΔX_med, σ_ΔY_med, σ_ΔZ_med, and the maximum and the minimum of each of them (Table III).

V. CONCLUSION

The terrestrial photogrammetric systems described in this article are not "professionals" methods. However, the gained results confirmed the possibility of use them as either complementary or alternative methods to the more professional surveying techniques. The field photogrammetric part of the whole work needs less time as usual, whereas the 3D modeling and representation time are remarkably reduced. The realization costs are quite low because they are represented by the purchase of a high quality off-the-self digital camera, with a sensor of at least 6 Mpixel, and the purchase of a Fotogram software licence, with a total cost of about 1000 Euro.

Finally, the AutoCAD environment reduces remarkably the training times and increases the number of operators that can complete autonomously a 3D surveying in a short time.

REFERENCES


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<tr>
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<td>ΔX_med ±σ_ΔX_med</td>
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<td>ΔX_max</td>
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Reference:


