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Imaging rover technology: characteristics, possibilities and possible improvements

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Abstract. The terrestrial photogrammetric survey allows to acquire geometric characteristics of objects quickly and with handy and inexpensive hardware. Traditionally, these measurements require some hours of time between the choice of the acquisition points, the setting up of the camera, the survey of the topographic support network and subsequent processing of the acquired data. The upcoming of advanced algorithms such as "structure from motion" (SFM) [1] and the recent availability of optical cameras with increasing resolution combined with increasing resources of mass storage [1], make it possible to create dedicated hardware with potentials not possible with these technologies so far. Of particular interest in this field is the coming of so-called "imaging rovers", i.e. cameras that allow simultaneous acquisition of multiple images, covering a 360-degree panorama and in some cases, directly positioned thanks to GPS/GNSS differential receivers with centimeter accuracy. The recent availability of these innovative techniques requires careful verification to assess their capabilities, accuracy, precision and possible limitations. This work presents the first systematic verification of one of these latest generation devices in different conditions and for different applications. It has been verified that in many cases it is possible to obtain three-dimensional surveys quickly with information contents comparable to those of more expensive and less handy instruments such as terrestrial laser scanning. The development of these techniques could lead to operational simplifications and greater efficiency also in complementarity with the reliefs from UAVs that, as it's well known, show some limitations in the so-called urban canyons.

1. Introduction

Terrestrial photogrammetry techniques are emerging as fast and effective survey techniques for different types of applications [1, 6] and in some cases is supplanting the more consolidated technique of terrestrial laser scanning [7,9].

"Imaging Rovers" are integrated systems made up of several cameras that are able to capture 360° panoramas in such a way as to obtain a complete visual documentation of the detected area and at the same time a measurement of the surrounding environment.

In practice an Imaging Rover is a mobile device containing multiple integrated cameras that are able to capture a panoramic view. Usually, when capturing images, a prism or an RTK receiver is connected to the camera to record its position. Each time the camera captures a series of photos, a photo station is created, which defines a point and includes the coordinate data, images and all raw sensor values, i.e. the position of the station that has not yet been compensated.

The Trimble V10 Imaging Rover (Fig.1) was extensively tested in this experiment. With a total of 12 calibrated cameras, seven panoramic cameras and five cameras oriented downwards, it enables the capture of an entire panoramic image of 60 MP (5 MP per image). These images provide a complete documentation of the site under study, which can then be used for photogrammetric measurements.

Figure 1. The imaging rover combined with GPS/GNSS receiver (on top) during the survey of “Pozzo del Merro”.

This metric imaging capability is one of the strengths of imaging rovers as it is ideal for performing a job that consists of a large amount of data to be collected, or when the site characteristics are complex or difficult to capture. Consider that in “classical” terrestrial photogrammetry a relative orientation between the different acquisitions is needed while with such devices the relative orientation between the 12 acquisitions of each station is known. On the other hand the absolute orientation can be estimated from the GNSS differential receiver positions.

2. Test sites

In order to correctly evaluate the capabilities and limits of rover imaging, an extensive series of tests was carried out, using the instrumentation in areas with very different morphological and geometric characteristics, this in order to be able to evaluate the possibilities and limits in the most extensive manner.

In particular, the IR was used under significant real conditions at the following sites, all in Italy:

- Emperor Augustus' sundial, Rome
- Basilica of Collemaggio in L'Aquila
- Palace Square in L'Aquila
- Controlled landfill of municipal solid waste near Rome
- Karst cave called "Pozzo del Merro", Sant'Angelo Romano

Only the first site was completely indoor so a total station survey was needed, for the remaining surveys only the GPS differential positioning was used for the external orientation. The surveys of the first two sites have given satisfactory results both in terms of metric accuracy and in terms of completeness of the survey, the results of these surveys have already been presented in previous communications [10,11] and will not be repeated here.

On the remaining sites problems of completeness of the data were observed and therefore the study of the data processing was deepened.

Already in the data processing for the Sundial of Emperor Augustus [12] it was observed that the results could depend very much on the software used for the processing of photos to SFM, highlighting among other things that non-specific software could obtain more complete results than the version of proprietary software then available Trimble Business Center (TBC) 3.5. [13] Without entering into the merits of the metric accuracy obtainable from specific software and generic software, however, the difference in completeness of the final data was unexpected as the specific software can read all the calibration information of the cameras and the relative and absolute orientation of the cameras themselves, while the generic software cannot do so and therefore has fewer parameters to reconstruct the absolute orientation of each individual frame. For this reason, it was decided to repeat the last 4 processes with an updated version of the specific software in order to evaluate the results and possible improvements in the reconstruction of the photogrammetric model. Below are the results and specific statistics of the modelling for the two elaborations.

3. Palazzo Square in L'Aquila

The site is a historic square in the city of L'Aquila, hit by the 2009 earthquake [14], on which laser

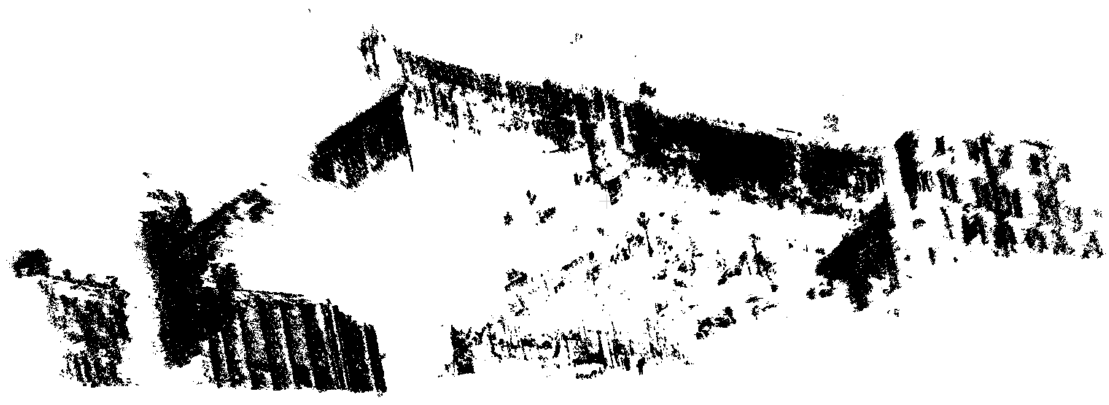

Figure 2. First points cloud restitution of piazza Palazzo.

scanning, UAV, and total station surveys have already been carried out, allowing a comparison in geometric terms[15].

The completeness of the reconstruction of the square during the first elaboration of the survey was not completely satisfactory, leaving many areas not reconstructed in a satisfactory way, in particular those of the flooring, as shown in figure 2 for this reason, after a comparison with the manufacturers of the instrument, it was decided to repeat the elaborations using the new version of the specific software (TBC 4.1) obtaining certainly more complete results already at a first examination of the point cloud, comparing, for example, the monument in the center of the square (Fig.3).

It should be noted that here, as in the subsequent tests, all the configurable parameters were left at the default values and the tie points were automatically chosen, this in order to make the elaborations as objectively comparable as possible with each other, it is certainly possible to improve the results by appropriately calibrating the initial parameters.

This improvement can also be observed from the analysis of the photogrammetric parameters of frame orientation shown in Table 1 below, where it should be remembered that in this case the reference factor, also called standard error of the unit weight, is the ratio between the evaluations of residuals a posteriori and those a priori.

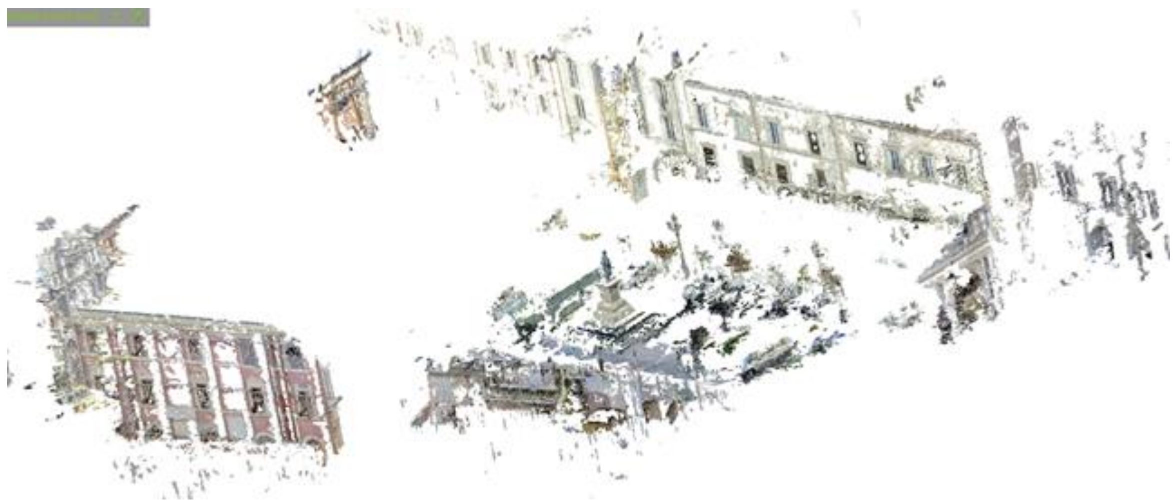

Figure 3. Second points cloud restitution of piazza Palazzo.

The appropriate value is between 0.95 and 1.05. This factor is reported in general but also distinguished in the group photogrammetry and inclination. Optimal weighting is achieved when the reference factors in the groups is close to 1.

	First elaboration	Second elaboration
Station geometry (0 to 10)	0	0
Observation precision (0 to 10)	5.7	9.7
Tie point distribution (0 to 10)	10	10
Tie point geometry (0 to 10)	3.7	5.6
Tie point redundancy (0 to 10)	9.1	2.9
Equations number	2758	5100
Unknowns number	1095	2970
General reference factor	1.52	0.59
Iterations number	5	5
Photogrammetric reference factor	1.53	0.59
Inclination reference factor	0.62	0.14

Table 1. Statistical parameters changes between first and second elaboration of the square.

4. Controlled landfill of municipal solid waste near Rome

The second test site is a controlled landfill of solid urban waste located near the city of Rome, the morphological characteristics are much simpler than the previous site and there are fewer requests for accuracy necessary to monitor such a site. The site also differs in the weaving of the surfaces to be restituted, which consist of waste and landfill. The surveys of these specific sites could benefit considerably from the speed and simplicity of acquisition with IR as the safety regulations require the total suspension of the work activity during the survey with obvious additional costs to those of the survey. In this case the results have improved in general, giving more details in the lower part and less details in the upper part (Fig. 4).

For this specific type of survey the result is an improvement as it is not necessary to have a high density of points, due to the irregular characteristics of these surfaces, but it is necessary that the points are evenly distributed throughout the area and the second return is certainly more homogeneous. In this case it can be observed that the statistical parameters between the two tests do not vary significantly (Tab. 2).

	First elaboration	Second elaboration
Station geometry (0 to 10)	10	10
Observation precision (0 to 10)	9	9
Tie point distribution (0 to 10)	9.8	9.8
Tie point geometry (0 to 10)	3.9	3.9
Tie point redundancy (0 to 10)	4.9	4.1
Equations number	6682	6448
Unknowns number	3459	3462
General reference factor	0.93	0.93
Iterations number	3	3
Photogrammetric reference factor	0.92	0.93
Inclination reference factor	1.7	1.06

Table 2. Statistical parameters changes between first and second elaboration of the landfill.

Figure 4. First (on the left) and second restitution of the landfill

5. Karst cave called "Pozzo del Merro", Sant'Angelo Romano

The last test site is the karst cave called “Pozzo del Merro”, which represents the most evident manifestation of karst in the area [16,17].

Currently the cave, situated in Sant’ Angelo Romano(Italy) is considered the second deepest flooded karst cavity in the world with its 392 meters of depth explored so far [11] but bathymetric surveys are in progress to verify whether the depth of the submerged part is even greater. The site, which houses some rare and endangered species of flora and fauna, had already been surveyed in the emerged part with lasers and total station and a first comparison with IR had already been done [18].

The morphology is complex with very steep slopes and covered by a very dense vegetation this had required days of work for the surveys with lasers and traditional instruments, the same survey with IR was performed in a few hours.

Figure 5. 3D models of the cave

	First elaboration	Second elaboration
Station geometry (0 to 10)	9.1	0
Observation precision (0 to 10)	9.1	1.9
Tie point distribution (0 to 10)	4.6	10
Tie point geometry (0 to 10)	9.2	10
Tie point redundancy (0 to 10)	4	0
Equations number	133	150
Unknowns number	75	114
General reference factor	0.96	0.03
Iterations number	4	8
Photogrammetric reference factor	0.94	0.03
Inclination reference factor	1.11	0.01

Table 3. Statistical parameters changes between first and second elaboration of the landfill.

The first elaboration had provided extremely fragmentary results and not sufficient for a complete restitution (Fig.5) but the second elaboration significantly improved the results allowing a decidedly more precise reconstruction of the previous elaboration. In this case some of the statistical parameters have enhanced but the most part of them have degraded(Tab. 3).

6. Conclusions and future developments.

The current results show that in addition to the geometry and mode of acquisition, the algorithm of data processing through techniques generically related to SFM has a big influence on the final result.

In particular, it has been observed that the results can vary with the same original images and geometry of the acquisition, even simply according to the specific release of the software package.

We think, also on the basis of previous experiments, that even non-specific software could provide improvements compared to standard procedures.

However, imaging rover technology has shown that, in some situations, it can provide results comparable to those of other techniques that are operationally more expensive in terms of logistics and time.

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