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Efficiency Evaluation of Processed Photogrammetric Data Captured by GPS Digital Camera

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Abstract: Recent developments in the acquisition and processing of close range images is an aim of primary importance in photogrammetry and computer vision, for digital documentation and reconstruction of objects featuring different characteristics. This demand is increasing in various fields, such as Cultural Heritage, Computer Graphics, Robotic and many other. For this reason, the digital image–based technique has been extensively used to produce high quality 3D models of heritage sites and historical buildings for documentation and preservation purposes. The features of any 3D model are highly dependant on the use of that model and can be very variable in term of accuracy and time for their creation. In the current paper, a certain digital measuring scheme based on a GPS-enabled digital camera (RICOH Capilo 500SE) is thoroughly tested and investigated for its capability in 3D modeling, as a complementary research in the same field. A practical field experiment showed a positional accuracy reported by this system was about 0.42 m in the 3D coordinates of some selected object points on a photographed façade captured by this camera. This accuracy is optimistic since the taken images were processed with only one control point, as a saving tool in time and cost of data acquisition. Moreover, this digital system can be used as a Mobile Mapping System MMS in some applications under certain circumstances and precautions. As an overall evaluation, this combined digital system should be subjected to more researches for the time being and further modifications and enhancements in the future.

Key words: Close range photogrammetry · Heritage documentation · GPS · Digital camera

INTRODUCTION

Accurate surveying for data acquisition and processing is a key factor for cultural heritage preservation and valorization, particularly on complex objects or when the 3D model requires different levels of details. So, any adopted survey must be capable to produce an accurate geometric and qualitative description of the current situation of the structure in the shortest time [1]. In this field, there is no single technique that can be considered the best for all 3D modeling applications to give satisfactory results in all situations, concerning high geometric accuracy, portability, automation, photorealism and low costs, since available techniques vary in accuracy, reliability, ability to capture details and their level of automation. Therefore and despite of the potential of each single technique, it is often very useful to combine data obtained from different technologies, in order to get the optimum benefits and ensure the correctness of modeling complex structures [2, 3].

Digital documentation of cultural heritage sites and objects is becoming a very important field of applications for 3D modeling and reconstruction. Consequently, digital photogrammetry is one of the most rapidly developed, cheap and easy phenomena that uses recent digital cameras with great storage capacity and digital photogrammetric measuring approaches. In this context, close range digital images along with the considerable improvements in photogrammetric software can be considered as the most commonly used input data for reconstructing building facades automatically or semi-automatically with excellent precision [4, 5]. The accuracy and/or realistic level of the building façade models are vital for documenting and reconstructing the historical and cultural heritage buildings. Accordingly, the correct interpretation of images showing building scenes is a challenging task, due to the complexity of the scenes and the great variety of building structures and details [6].

Moreover, another special challenge, which is more important than that occurring in photogrammetry, was achieved in the field of spatial data collection through

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the use of satellite systems [7]. In this case, Global Positioning System (GPS) comes into use even in terrestrial photogrammetry especially in architectural and archeological photogrammetric studies and works to perform the absolute geo-referencing of the area and the description of the structure. Thus, in accordance with digital photogrammetry principles, GPS can determine the perspective center's coordinates of the used digital camera mounted few decimeters above the ground on a tripod. Consequently, this combined digital close range photogrammetric system incorporates real time location information and map information, which saves time and creates economic efficiency [8], since in most cases real time reconstruction is necessary. This is done by minimizing needed ground control due to the decrease in number of unknowns through the use of a GPS digital camera providing the coordinates of the exposure station.

Accordingly, the main purpose of the current study is to test the efficiency of a new combined digital close range photogrammetric system (digital camera equipped with GPS), as an auxiliary measurement and mapping tool, for documenting a building façade to be reconstructed in a 3D model. To achieve this purpose, the description of the used instruments as well as the photographed façade along with the main characteristics of the used combined digital system is outlined first. This includes the chosen GPS control points, object points and acquisition of digital images. Then, the criteria of assessment for evaluating the obtained results is presented and analyzed. Finally, the output main conclusions along with some appropriate recommendations will be given.

DESCRIPTION OF THE FIELD EXPERIMENT

A brief on the different instruments used in the current research is outlined first, followed by a brief on the field experiments including the needed ground control system and the used image configuration and specifications, in addition to the data processing technique.

Used Instruments and Techniques: The main device used here is a stand alone digital camera equipped with a GPS receiver, namely, RICOH Capilo 500SE GPS camera shown in Figure 1. This RICOH Capilo camera - GPS camera - here after, has a solid state CCD (Charged Coupled Device) image sensor of 8.0 Megapixels. It is available with an integrated GPS receiver and a digital compass. A very useful capability of this camera is that the latest GPS information is retained in the camera for ten minutes whether logged or not on GPS satellites. This enables to acquire GPS information outdoors in the

Fig. 1: Used RICOH Capilo 500SE GPS digital camera http://www.korecgroup.com/images/images_img-229.jpg

nearest place required of the indoor exposure station and then shoot images indoors using the pre-saved GPS information. This of course could be very handy, especially in Monumentation and documentation of buildings' façade in closed area with no GPS satellite coverage.

For evaluation purposes, two kinds of GPS receivers are used, the first is a Trimble R3 precise GPS geodetic receiver used for referencing of precise coordinates, while the other is a Garmin Venture GPS navigator used for the assessment of the used technique. In addition, a Topcon 712 GTS total station was also used for the survey of the chosen points precisely relative to a local coordinate system.

The Photographed Facade: In order to achieve the sought objective of the current study and demonstrate the potential of such system, a certain field experiment has to be designed for this purpose. Since the core of this study concentrates on documenting building facades accurately and economically, which encompasses several geometrical details using close range photogrammetry, the test field area was chosen to be the architectural frontal of the main building of the faculty of Engineering of Ain Shams University. This façade, whose captured image will be presented later in this section, has many architectural features like windows, doors, columns, stone blocks interlock and arches with a variety of geometric details that will nearly suffice our requirements here.

Since these existing features have to be modeled accurately as a three-dimensional (3D) presentation for documentation purposes, this implies the choice of well defined sharp object points, well distributed over this selected area to be photographed and also should be sufficient in number for any further computations and analysis. Figure 2 shows a sketch drawing for an elevation view of this investigated façade along with the chosen fourteen (14) object points. This elevation view was drawn without any calculations or measurements to represent its general layout, just to illustrate the distribution of all selected target object points within this

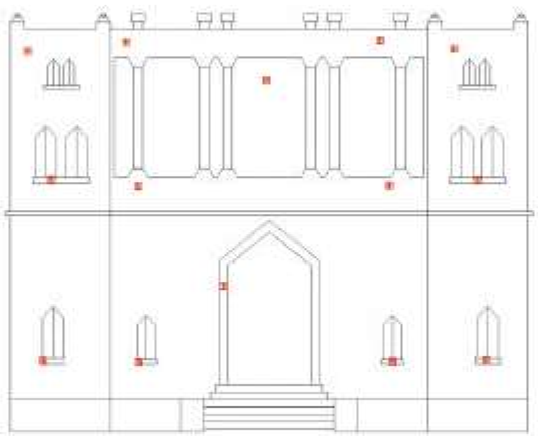

Fig. 2: Elevation view of the used building façade along with the chosen test points

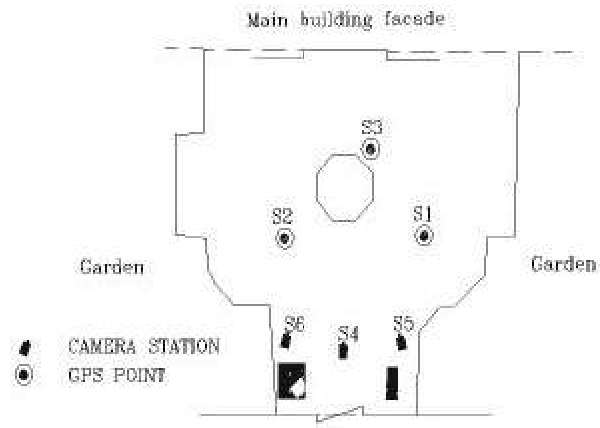

Fig. 3: General layout of the GPS ground control points and location of the three different camera stations

photographed façade. These object points will serve as both control and check points.

The GPS Control Points: The field procedure here in requires the availability of some kind of ground control points to be used later as reference in the documentation survey of the photogrammetric approach, for assessment of the current investigation, as well as other terrestrial points to act as exposure stations of the used camera. Therefore, three ground control points are chosen namely S1, S2, S3, where as their ground coordinates were computed by precise and adjusted GPS observations to act as check points in order to compare the newly used approach with the traditional technique requiring the availability of ground control. These points constitute the reference system by which the coordinates of the other 14 object points placed on the façade were determined by total station observations. In addition, three stations named S4, S5 and S6 are chosen as exposure stations for the used GPS camera. The location of all these - previously mentioned - six points is chosen in an open area to ensure high GPS coverage with a low mask angle as well as to be least affected by multipath. Figure 3 shows a layout of the location of all chosen GPS control points as well as the three exposure stations.

Acquisition of Digital Images: The selected building facade was captured from the three exposure stations varying in both scale and orientation, as indicated previously in Figure 3. These exposure stations were placed in such a way that nearly all chosen target object points appear in each photo taken by the camera at each station, besides the three GPS base stations, as clearly depicted in one of the taken images presented in Figure 4. The GPS coordinates of the exposure station position are automatically determined when the camera is switched on. The compass can automatically capture the direction and the horizontal tilt angle in which the picture was taken. Accordingly, by integrating both the GPS device and the compass directly into the camera, this combined digital system covers the whole working process from position localization, over image acquisition to data transfer and store information about the position and the direction in the EXIF header of the picture. In addition, the attached GPS PhotoMapper software enables the connection of photos with their location and the integration into a Geographic Information System (GIS). This software allows the utilization of the saved information to be integrated into the geographic information system ArcGIS from ESRI where the photos can easily be administered by the GIS user. Additional information on this state-of-the-art camera and detailed specifications can be found in www.ricoh.com.

Shortly, many advantages are gained such as: Selection criteria are offered during the loading process of the photos into ArcGIS, e.g. the date or time the photos were taken. Thus, long and frustrating searching procedures in archives belong to the past are eliminated. Ability to control disasters since the situation is recorded with exact time and position information. Finally, it is useful in classical object documentation and administration activities since long working hours in the office for georeferencing captured images has been saved

Fig. 4: Digital photo taken at one of the exposure stations

Fig. 5: Fixation of the GPS camera over the tripod

because most data is collected automatically with the GPS camera and GPS PhotoMapper. It should be noted here that, the camera is held over a tripod during capturing the images and fixed in such a way to control its position and orientation, as depicted in Figure 5.

Photogrammetric Data Processing: Bundle adjustment is the most appropriate method used in digital photogrammetery since it depends on analytical principals as well as being a numerical technique. Colinearity condition, which depends on aligning the points on object, perspective center of camera and on the image of the object, is the algorithm that forms the mathematical model of the GPS supported terrestrial photogrammetry. It relates both image coordinates system and GPS object coordinates system through the intrinsic and extrinsic orientation parameters of the camera. In this context, minimum of three ground control points should be located in the overlapped area to orient any stereo-pair. If the object is visible on three or more images, bundle adjustment solution is possible including all available measurements at the same time [9]. Preserving the final accuracy of the bundle solution with decreasing the number of required control points is a challenging task in terrestrial photogrammetry, which can be the main core and goal of the current research. In this terminology, the absolute position of the mapped features can be determined and evaluated by directly georeferencing the camera station using the detachable GPS module with less control points [10].

The 3D reconstruction process based on digital close range photogrammetry can be divided mainly to orientation, measurements and modeling. So, automatic reconstruction depends on the automation of these procedures [11]. Hence, the Leica Photogrammetric Suite (LPS) Ver. 9.3 is the used digital photogrammetric workstation for processing three captured images at S4, S5 and S6 to extract 3D coordinates using the technique known as image correlation. It is a commercial software module within the larger IMAGINE package distributed by Leica Geosystems, which has a collection of seamlessly integrated tools providing accurate and production-oriented photogrammetric output.

METHODOLOGY OF INVESTIGATION

In order to assess the accuracy of the used combined digital system for 3D reconstruction of a certain façade, it should be a referenced or relative to a datum for comparison. Accordingly, the 3D ground coordinates of the three base GPS ground control points

S1, S2 and S3 and the placed object points, computed from geodetic GPS receivers and total station respectively, will be the base for such comparison. Hence, the corresponding computed 3D coordinates of the same object points resulted from the processed images using the LPS software will be assessed related to these reference coordinates. To achieve the above-mentioned objectives of this current research, the digital bundle solution will be carried out under two main study cases. Both cases differ according to the treatment of the extrinsic orientation parameters (exposure station coordinates and rotation angles) of the captured images, in which the former case treats those parameters as unknown values whereas the latter considers the exposure stations coordinates are only known as fixed values, taken from the GPS receiver embedded in the camera. On the other hand, each case will be solved twice according to the type of the involved control points, whether they are GPS stations or placed object points.

In all study cases, two evaluation criteria have been suggested to completely test the efficiency of this digital system. The first criterion is concerned with the discrepancies at the selected object points, as they were evaluated as the difference between the reference values and the corresponding computed ones from each bundle solution. In this case, the principal statistical parameters of these discrepancies, namely the maximum, mean and minimum as well as Root Mean Square (RMS), for single discrepancy determination will be evaluated. The second criterion pertains to the structure of the output covariance matrix of the 3D coordinates of all object points.

PRESENTATION AND ANALYSIS OF THE FIELD EXPERIMENTS RESULTS

This section is devoted to the manipulation and discussion of the results obtained from the solution of the captured three images that include the tested façade along with all selected object points. Those images were taken nearly 35.0 m away from the façade with the used camera zoomed to the standard focal length of 5.8mm. The LPS software was used twice to get the 3D coordinates of all object points, for previously-mentioned two cases of treating the extrinsic orientation parameters of exposure stations.

Stand-alone Digital Camera: In this initial experiment, the entire measuring and processing scheme was carried out, where as the exposure stations' orientation parameters of the digital camera are completely unknown. In this case, the images are scaled and oriented to the three geo-referenced ground control points computed from precise and adjusted GPS observations. Table 1 lists the statistical information of the output discrepancies in the 3D directions and the corresponding spatial positions for all 14 chosen object check points. This information includes the RMS of such discrepancies as well as the standard deviations (SD) of the computed 3D ground coordinates. Note that the X-direction is taken parallel to the building façade, Y-direction is perpendicular to the building façade pointing towards the building, while the Z-direction points upwards.

From this table, it is obvious that close range photogrammetry (close range images captured by the used camera and processed by digital software) is suitable and powerful in architecture and 3D building models, since its associated positional accuracy is in terms of few millimeters. It should be noted that and according to the methodology of investigation, another bundle solution is carried out using three object points as control points, well distributed on the façade. A non-significant degradation in all discrepancies information is occurred, but still considered as promising values.

GPS-Enabled Digital Camera: In this second case, the camera position and orientation at each observing station was extracted from both attached GPS receiver unit and digital compass. As stated before, the camera is held on the tripod in such a way to control and fix the 3D coordinates of all exposure stations, besides considering the rotation angles are nearly the same at each exposure station. Accordingly, this leads to the possibility of decreasing the required number of control points. In this context, two different bundle solutions are investigated to test the efficiency of the used GPS-enabled camera. The first solution is performed with only two control points, once while fixing the 3D coordinates of all exposure stations obtained from the attached GPS receiver called "Coordinate Fix" and the other while fixing the rotation angles at the three exposure stations, obtained from the camera's compass called "Rotation Fix". The second solution is performed with only one control points and fixed 3D coordinates of all exposure stations, as well as considering the rotation angles of one of the exposure stations being also fixed. It should be noted that, this configuration of bundle solution was preferably selected, since the errors of the rotation angles at each exposure station have more influence on the final positional accuracy than the corresponding errors in the exposure station coordinates [12], as will be verified also in this practical field experiment.

Table 1: Statistical Analysis of the Output Results of the Stand-Alone Digital Camera

Tested Direction	*RMS of Discrepancies (mm)*	*SD of computed Ground Coordinates (mm)*
X-direction *(along the façade)*	1.28	0.21
Y-direction *(perpendicular to the facade)*	2.74	0.46
Z-direction *(vertical)*	0.98	0.32
Spatial Position	3.18	-----

Table 2: Statistical Analysis of the Output Results of the GPS/Compass Digital Camera

			Two Control Points		
Statistical Parameters			*Coordinate Fix*	*Rotation Fix*	*One Control Point*
Discrepancies (cm)	X-direction	Mean	12.6	16.9	18.0
		RMS	14.2	18.6	19.7
	Y-direction	Mean	19.8	26.4	30.1
		RMS	22.1	29.8	33.7
	Z-direction	Mean	8.5	12.1	12.8
		RMS	10.5	13.4	14.9
	Spatial Position	Mean	26.7	34.5	38.7
		RMS	28.3	37.6	41.8
SD of 3D Coordinates (cm)		SDX	3.5	4.1	4.7
		SDY	4.9	5.3	6.1
		SDZ	2.7	2.9	3.0

Table 3: Ground Coordinates Discrepancies between Both Used Digital System and GPS Navigator Compared with the Precise GPS Observations

		Discrepancies (m)		
Station Name	*Observation Method*	*Latitude*	*Longitude*	*Altitude*
S1	GPS Navigator	1.203	1.192	0.915
	Used System	0.651	0.468	0.558
S2	GPS Navigator	1.547	2.202	0.923
	Used System	0.873	0.782	0.514
S3	GPS Navigator	0.931	0.636	0.889
	Used System	0.452	0.368	0.423

Table 2 shows the corresponding statistical parameters of the object points' resulted discrepancies in both bundle solutions. It indicates an expected deterioration in the positional accuracy of the computed coordinates, related to the precision of both GPS receiver and digital compass as well as the reduction of the involved number of control points. Analyzing these listed results still gives attractive findings; since a positional accuracy of about 0.42 m was achieved using this combined digital solution with only one control point in the 3D modeling of the photographed façade.

Similarly, the same bundle solutions are performed but with the other type of the object control points, which are observed and computed by the total station as previous but with the other three. Also, nearly the same positional accuracy deterioration occurred at the remaining object points. In addition, Table 3 indicates the discrepancies at the three GPS stations when using only one control point. These discrepancies are computed at each station as the difference between the references coordinates from GPS precise observations and the corresponding ones computed by using both the tested combined digital system and the hand-held navigator. Accordingly, the used digital combined system is better when compared to the navigator GPS observations, concerning the smaller discrepancy values at each station. Moreover, processing the images with fixed exposure stations coordinates obtained from the attached GPS receiver exactly gives better results than considering the corresponding coordinates as fixed values using the GPS navigator.

Finally and in order to make a concise efficiency evaluation of the used combined digital system, another solution was run by the LPS without using any control points. In this case, all extrinsic orientation parameters were taken directly form the information provided and displayed by the GPS receiver unit and the digital compass. The corresponding results give a positional accuracy as a RMS value of nearly 89.0 cm, which completely matched with those issued by Scarmana [10] as 83.0 cm for processing only a stereo-pair with this system. Of course, the more images taken, the more degradation in the positional accuracy, due to the fixation of all considered extrinsic orientation parameters. Hence, this situation is not recommended in complex 3D modeling but may be useful for other applications that require timeless data acquisition and moderate positional accuracy.

CONCLUSIONS

Based on the results obtained from the practical field experiment discussed in the present investigation, the following conclusions are enumerated, along with some recommendations:

- Close range images processed by digital photogrammetric software are suitable for 3D modeling of structures, due to its great improvements in the positional accuracy as well as its versatility.
- The used combined digital system is efficient to be implemented in many applications, such as architecture measurements and complex structures models, according to its final accuracy as 0.42 m, even in the case of using one control point while processing three captured images.
- As expected, errors in the attitude (rotation angles) values of any camera station given by the digital compass will affect greatly the final spatial positioning compared with the corresponding errors given by the attached GPS unit.
- The used GPS-enabled camera (Ricoh 500SE) can be considered as a Mobile Mapping System MMS, for its capabilities compared with its cost and time in data acquisition.
- Processing the images captured by this camera without control points is not suitable for 3D modeling, but can be used in applications that to somehow do not necessitate precise height information such as Earth works.

Hence, several challenges should be still considered concerning the generalization and utilization of a GPS enabled digital camera to be used widely as a Mobile Mapping System MMS. These challenges may include increasing the positional accuracy given by the attached GPS receiver and mainly the digital compass in such a way to control the attitude of the camera at the exposure epoch. In addition, more research can be performed to investigate the influence of each displayed information concerning the attitude (each rotation angle) and position (each component of the 3D ground coordinates) of exposure stations on the final positional accuracy.

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