A LOW-COAST MMS INTEGRATING GPS, DIGITAL COMPASS AND A CAMERA TO THE DIRECT GEOREFERENCING OF DIGITAL IMAGES

Margherita Fiani[a] , Pasquale Pistillo[a]

[a] Dipartimento di Ingegneria Civile, Università di Salerno, Via Ponte Don Melillo, 1 - 84084 Fisciano (Salerno), Italy
(m.fiani, ppistillo)@unisa.it

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ABSTRACT :

A low-cost, easily transportable Mobile Mapping System (MMS) was designed and built to obtain the direct georeferencing parameters of images; its components are a GPS receiver, a digital compass and a digital camera.
The main aim of the system is to directly define the orientation parameters of an image. The accuracy of the 3D coordinates of the points belonging to the object photographed is a consequence of the whole process which involves GPS positioning, compass angle determination, system calibration and any other useful auxiliary data that can be used to improve the accuracy of the system (GCPs coordinates, distance between the object and the camera, etc.). The tests carried out up until now have demonstrated the "theoretical" huge potential of the measuring system as well as its versatility. This system could in fact be used to carry out surveys using vehicles such as cars, helicopters and boats.

1. INTRODUCTION

The validity of photogrammetry in surveying areas that are either difficult to reach or to operate in is evident, considering that it is possible to describe the territory without actually having to go over it. There is, as well, a high degree of accuracy, depending on the scale of the frames. The degree of accuracy also depends on the aim of the survey as well as the scale of the map produced.
Nevertheless, there are cases when classic photogrammetry does not give satisfying results. This is the case with the Amalfitana Coast in Italy, a hydrological risk area, considered to be of high environmental value and protected by UNESCO. The verticality of the rugged coasts, with the added feature of all the coast walls facing the sea as well as the particular lay out of the road that runs along it, make it almost impossible to follow the standard procedure of placing a camera on solid ground and positioning the Ground Control Points (GCPs) on the cliff.
In order to overcome this problem, we have decided to use a motorboat with a digital camera and GPS aboard, thus making it easier to reach any isolated areas and photograph them from the most suitable position. The movement of the boat (roll and pitch) made it difficult to set the exterior orientation of the camera, necessary in order to know with precision the changing position of the centre of the camera lens. A low-cost, easily transportable system was built and tested, to reduce the problems created by the difficult conditions under which the survey was carried out. The system was made up of the following:

- Digital camera;
- GPS receiver;
- Digital compass;
- Portable Computer.

The aim of this study is to verify the efficiency and the correspondence to pre-set precision requisites of non-standard techniques used in surveying difficult-to-reach vertical surfaces. The possibility of carrying out a survey from a boat, with corresponding operative efficiency and reliability requisites will also be studied. The system was field-tested on the tower at Cetara (SA) and will subsequently undergo testing along the Amalfitana Coast, from a motorboat, in order to assess both precision and actual productivity.

2. DESCRIPTION OF THE MEASURING SYSTEM

A prototype measuring system called *POLIFEMO* (see figure 1) was designed and built to obtain the direct georeferencing parameters of selected images.

Figure 1. Diagram of the Mobile Mapping System *"POLIFEMO"*

The system was made up of an aluminium bar measuring approx. 30 x 10 x 1cm with perfectly flat and parallel sides. A digital camera was fixed in the centre and a GPS antenna onto one of the ends. A compass was mounted onto a 30 cm aluminium support that was then attached to the bar in order to increase the distance from the camera, with the aim of accurately measuring the angles. All the measurements, absolute and relative between the various elements of the system were calibrated to the order of the millimetre. The bar was then screwed onto an adaptor that allowed it to be positioned using a standard topographic base.
The hardware components of the system are described in the following section.

2.1 The system's hardware components

A NIKON D1H digital reflex camera with interchangeable lens was used. The camera has an RS-232C interface serial port that can be used to connect it to a GPS unit thereby registering the information related to the position of the GPS antenna at the time of shooting. A hyper-focal lens with a main auto-calibrated distance of approx. 35mm was used. Pixel size is 11.80 µm.
Two double frequency *TRIMBLE 5700* GPS receivers were used for this study. The receiver is equipped with a *Zephyr* antenna.
The digital compass that we used is the *DMC-SX* produced by Leica Geosystem. It is a very compact sensor (33 x 31 x 13.5mm) capable of defining three angles (Azimuth A, Elevation E and Bank B) of the object on which it is placed, corresponding to the three standard photogrammetry angles K (drift), φ (roll), ω (pitch). Three sensors reading the terrestrial magnetic field while the Bank and Elevation angles by two inclination sensors set the Azimuth angle.
The nominal accuracy of the DMC is listed in table 2.

AZIMUT	0.5°
ELEVATION	0.15° at +/- 30°
	0.20° at +/- 45°
BANK	0.15° at +/- 30°
	0.20° at +/- 45°

Table 2. Nominal accuracy of the digital compass

The compass contains a chip that can be programmed via the interface serial port, allowing the operator to set the frequency and format of the output data. Several options include: the DMC either transmitting "raw" data at a maximum frequency of 150 Hz or first interpolating the data with a maximum transmission speed of 50Hz. DMC precision is therefore influenced by transmission frequency.The system can also correct the magnetic Azimuth angle by giving an appropriate declination angle as well as evaluate and compensate for the magnetic field distortions due to the presence of external sources, i.e. tools aboard the boat or high tension pylons. The compass contains a chip that can be programmed via the interface serial port, allowing the operator to set the frequency and format of the output data. Several options include: the DMC either transmitting "raw" data at a maximum frequency of 150 Hz or first interpolating the data with a maximum transmission speed of 50Hz. DMC precision is therefore influenced by transmission frequency.
The system can also correct the magnetic Azimuth angle by giving an appropriate declination angle as well as evaluate and compensate for the magnetic field distortions due to the presence of external sources, i.e. tools aboard the boat or high tension pylons.

3. HOW THE SYSTEM WORKS

At the moment of shooting, an impulse generated by the camera is transmitted through an electronic circuit that receives an input from the closure of the flash through a connector. This gives rise to the event-marker of the GPS and thus records the exact moment in which the image is acquired.
However, the raw GPS data is acquired within the receiver, which, simultaneously, transmits information to the computer regarding the time while the measurements carried out by the inclinometer are conveyed directly to the portable that stores them on its own hard disk. The frequency at which the compass transmits information received by the PC is 50 Hz maximum. Before the data is stored on the PC, it is couplet with information regarding the time which is transmitted by the GPS at a frequency of 10 Hz. The GPS and the compass are connected to the PC through two RS-232 serial ports. The PC receives the data and merges it using a proprietary synchronisation programme written in C^{++}.
In brief, at the very instant that the impulse generated by the camera releases the event-marker of the GPS, the compass measures the three orientation angles of the camera and the GPS allows for a determination of the position of the projection centre. Since all the data is connected to the same time and with knowledge of the time of the camera shot, it is therefore possible to determine the exterior orientation parameters of every single camera shot. The connection between the exterior orientation of the camera and the measurements carried out by the compass and the receiver is guaranteed by the fact that the receiver aerial, the camera and the inclinometer are positioned at reciprocal distances marked on the aluminium bar which was built to censure the perfect alignment of the axis passing through the centre of the three instruments and a connection both with the topographic tripod and also with the system of swinging. The flow diagram of the data is shown in figure 3, while figure 4 shows the aluminium bar design.

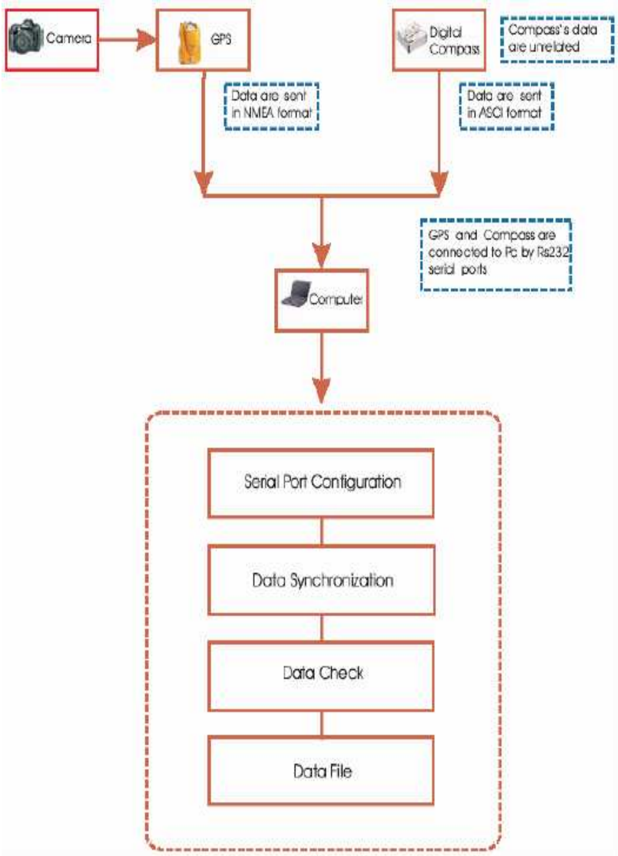

Figure 3. Flow diagram of the data and of the system

In conclusion, the *POLIFEMO* system supplies in output:

- a *.tiff image file, stored in the camera's memory
- a *.dat position file, stored in the memory of the GPS
- a time and angles of orientation file, stored in the PC .

This data must then be processed and merged so as to obtain the exterior orientation parameters of the camera.

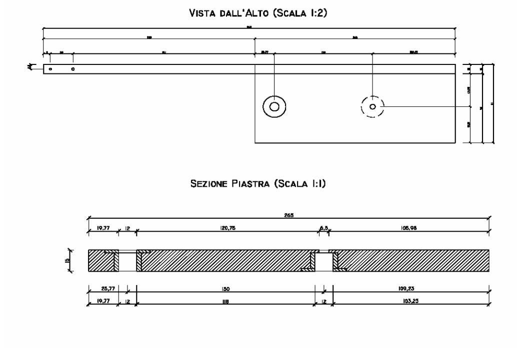

Figure 4. Diagram of aluminium bar design

3.1 Data acquisition and elaboration

The data obtained from *POLIFEMO* is complex, made up of:

- Data relating to the Position (spatial and angular);
- Data relating to the Time;
- Images.

There are different ways to process and store this data depending on the type.

The images are recorded on the camera's smart card, while the moment of shooting is memorised, along with the data relating to the spatial position on the GPS system's smart card.

The angular position data obtained from the DMC system, after being matched to the time data obtained from the GPS, is recorded on the hard disk of the computer, making it possible to compare the two. The storing of the images, of the shots and the spatial position data is automatic but a special program was written in C^{++} in order to synchronize DMC data acquisition with the times obtained from the GPS receiver.

An example of an output file can be seen in table 5. The compass was programmed to acquire data at a frequency of 50Hz while the temporal signal was emitted by the GPS receiver every 10Hz, therefore for every "GPS time" there are five values from the DMC.

Time	Az	Elev	Bank
17 01 39.20	132.7	4.15	-1.03
17 01 39.20	133.2	4.03	-1.10
17 01 39.20	134.1	3.99	-0.99
17 01 39.20	134.6	4.02	-0.90
17 01 39.20	133.5	4.11	-0.96
17 01 39.30	133.8	4.07	-0.98
17 01 39.30	133.6	4.09	-0.96
17 01 39.30	133.2	4.15	-0.96
17 01 39.30	133.8	4.11	-0.93
17 01 39.30	134.1	3.98	-1.00
17 01 39.40	133.9	4.11	-0.91
…………..	……	…	….

Table 5. An example output from DMC acquisition data software

The images do not need to be processed but the data stored in the GPS memory as well as that on the hard disk of the PC do, in order to obtain the exterior orientation parameters of the POLIFEMO System.

The GPS gives **.dat file* containing all the information relating to the spatial position of the WGS84 system GPS antenna mounted on to POLIFEMO as well as that relating to the moment of shooting. This file is elaborated by the *Geomatics Office* software developed by Trimble and then combined with the data from a fixed station, used as previously described, as a local reference point.

The final processing of the kinematically post processed data results in a file containing positional data (X, Y, Z) corresponding to the moment in which the camera took a shot in the Datum WGS84 (see table 6).

4. COMPUTATION OF EXTERIOR ORIENTATION PARAMETERS

The processing described in the preceding paragraph supplied the spatial coordinates and the angular values corresponding to the phase centre of the GPS aerial at the moment of the camera shot. One further processing phase is now required in order to obtain the exterior orientation parameters of the image, in other words, the spatial coordinates of the projection centre in the exterior reference system and the inner orientation parameters in relation to the exterior. To this end, a proprietary software was written in Matlab. The software input data is the following:

- the file generated by the software written in C^{++} for managing data obtained from the DMC (output in Table 5);
- the **.dat* file generated and processed by the *Geomatics Office* software (output in Table 6);
- the X, Y and Z coordinates in WGS84 of the selected point of origin of the Local Geodetic System (position of the master station);
- the acquisition frequency of the GPS and DMC data;
- the calibration file of the bar containing the geometric information regarding the reciprocal position of the components of the measuring system.

Figure 8 shows the relationship between the system components and the reference systems used. Note the assumption that the Local Geodetic System (the exterior system) and the System Body (linked to the compass) are parallel at rest (when $\alpha = 0$, $\phi = 0$ e $\omega = 0$).

Shooting Instant	X_{WGS84}	Y_{WGS84}	Z_{WGS84}
15 13 17.033066	4687573.368	1230034.929	4132778.563
15 13 17.044898	4687573.368	1230034.929	4132778.563
15 13 24.196690	4687573.368	1230034.929	4132778.563
15 13 24.206617	4687573.368	1230034.929	4132778.563
15 13 24.218686	4687573.368	1230034.929	4132778.563
………………...	………………	………………	………

Table 6. Output of the *Geomatics Office* software (only event markers)

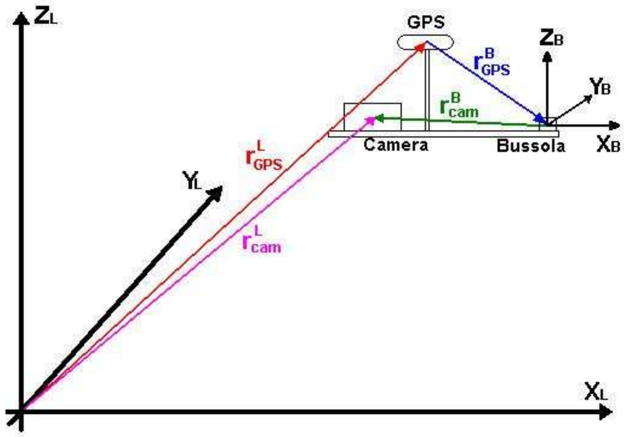

Figure 8. Relationship between the components of the POLIFEMO system.

The program carries out the following operations:

1. controls the internal coherence of the files, verifying that the number of certified lines coincides with the number of lines present inside each file; if the two do not match then the procedure is interrupted;
2. calculates with a linear interpolation the value of the Azimuth, Elevation and Bank angles at the moment of shooting;
3. calculates the rotation matrix R_B^L between the POLIFEMO System X_B , Y_B e Z_B and the Local Geodetic System X_L , Y_L e Z_L:

$$R_B^L = \begin{bmatrix} \cos\phi\cos\kappa & \cos\phi\sin\kappa & \sin\phi \\ \cos\omega\sin\kappa + \sin\phi\sin\omega\cos\kappa & \cos\omega\cos\kappa - \sin\phi\sin\omega\sin\kappa & -\sin\omega\cos\phi \\ \sin\omega\sin\kappa - \sin\phi\cos\omega\cos\kappa & \sin\omega\cos\kappa + \sin\phi\cos\omega\sin\kappa & \cos\omega\cos\phi \end{bmatrix}$$

4. passes from the WGS84 system to a system with parallel axis and with the origin that is the origin of the local geodetic system;
5. calculates the rotation matrix between the Local System and the WGS84 System:

$$R_L^{WGS} = \begin{bmatrix} -\sin(\lambda_W) & -\cos(\lambda_W)\sin(\varphi_W) & \cos(\lambda_W)\cos(\varphi_W) \\ \cos(\lambda_W) & -\sin(\lambda_W)\sin(\varphi_W) & \sin(\lambda_W)\cos(\varphi_W) \\ 0 & \cos(\varphi_W) & \sin(\varphi_W) \end{bmatrix}$$

1. calculates the coordinates of the centre of POLIFEMO within the Local Reference System;

$$r_{CAM}^L = r_{GPS}^L + R_B^L(r_{GPS}^B + r_{DMC}^B) \Rightarrow r_{CAM}^L = R_{WGS}^L r_{GPS}^{WGS} + R_B^L(r_{GPS}^B + r_{DMC}^B)$$

where:

r_{CAM}^L = position of the Projection Centre in relation to the Local System;

r_{GPS}^L = position of the GPS aerial in relation to the Local Geodetic System;

r_{GPS}^{WGS} = coordinates of the vector GPS Aerial – Local System Centre in relation to the WGS84 System;

r_{GPS}^B = position of the Phase Centre of the Aerial in relation to the System Body;

r_{DMC}^B = position of the Centre of Shot in relation to the System Body.

6. generates an output file containing the six exterior orientation parameters for every camera shot moment. An example of this output file is shown in Table 9.

Coordinates of the lens centre			Attitude		
X_0	Y_0	Z_0	k	ω	φ
70.3906	9.5925	1.5868	53°.6200	-5°.6840	38°.9360
70.3906	9.5926	1.5868	53°.6510	-5°.6747	38°.9143
70.3793	9.5651	1.6108	52°.1478	-4°.4100	38°.9266
70.3792	9.5653	1.6107	52°.1784	-4°.4100	38°.9051

Table 9. Example of the output of the software for calculating the exterior orientation parameters

5. FIRST EXPERIMENTAL RESULTS

The main aim of Polifemo is to directly define the six exterior orientation parameters of an image. The accuracy of the 3D coordinates of the points belonging to the object photographed is a consequence of the whole process which involves GPS positioning, DMC attitude determination, system calibration and any other useful auxiliary data that can be used to improve the accuracy of the system (GCPs coordinates, distance between the object and the camera etc.).
A test on the Tower of Cetara, in the port of the village on the Amalfitan Coast in Italy (see figure 10) was carried out in order to compare the orientation parameters obtained from Polifemo with those estimated indirectly through standard photogrammetry.
A three points polygonal (S1, S2 and S3) was materialized on the terrain, as seen in the figure, to survey the position of the GCPs using standard techniques. The position of the three points was also surveyed using the GPS in static mode. The coordinates of approximately 20 points were taken from both S1 and S2 using a Total Station *Leica TCRA1103*, some were signalled in advance, others were natural. How the GCPs were distributed can be seen in figure 10, put over a facade (from C. Carluccio). *Galileo 2000* software was used to elaborate the standard measurements.
The Polifemo system was then placed on C1 and a kinematic survey was simulated, placing the GPS master station on S3. Data acquisition including images, coordinates and angles, began after having synchronized the times (GPS measurements and the compass) with the software described in section 3.1.

The GPS data was kinematically post processed while data acquisition times and modality for the data coming from the compass, was varied each time in order to optimise the system as well as identify the best way to calibrate it.
The same measurements were also taken from C2, the location of the two stations can be seen in figure. The static baselines S3-S1 and S3-S2 were then measured in order to have double points to be used for the reference system transformation.
The data were then elaborated once the survey was completed, with the data acquired via Polifemo directly giving the six external orientation parameters of the images, as follows:

- the GPS baseliness were cinematically elaborated, to give the coordinates of both the phase center antennas at the time of shooting (event-marker);
- the angular values corresponding to the time of shooting were linearly interpolated;
- the coordinates in WGS84 system were transformed into the local geodetic system, by means of the three double points: S1, S2, S3;
- the spatial coordinates of C1 and C2 were finally calculated.

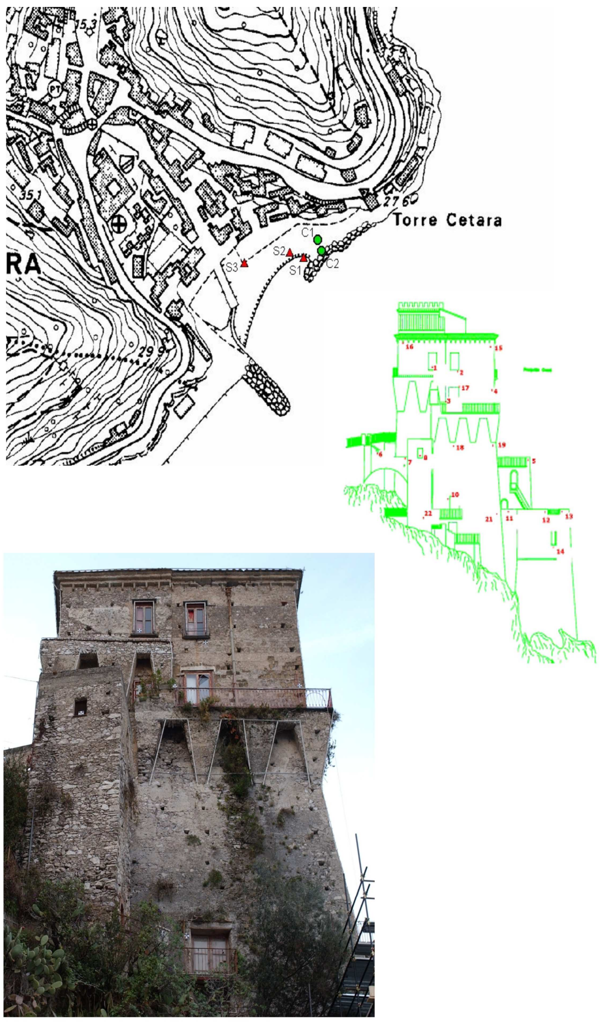

Figure 10. Test area: Cetara Tower (Salerno, Italy

The coordinates of the twenty two GCPs in a local geodetic system with the origin point S1 were calculated by elaborating the standard measurements. It is worth noting that not all the points were used, some because they were not stereoscopic, others due to problems that affected accuracy.
The two images were orientated by Stereoview 300 ver. 2.8.2 developed by Menci Software using the GCPs acquired giving excellents rsults in term of accuracy.
In order to compare the orientation parameters, those ones estimated by using photogrammetric technique have been transformed in the same local geodetical system in which the parameters estimated by Polifemo were computed.
The differences between the positioning parameters between the attitude parameters reach value that are doubtless quite high and can be explained only in part with the low accuracy related with the used compass. The parameters accuracy is probably also influenced by both the accuracy of the inner geometry of the camera and other causes that must be investigated.

6. CONCLUSIONS

The tests carried out up until now have demonstrated the “theoretical” huge potential of the measuring system as well as its versatility. This system could in fact be used to carry out surveys using vehicles that are not usually used such as cars, helicopters and boats. Nevertheless, the results of the test are not very reassuring. In the next experimentation we try to increase the precision by better calibrating the system and adding geometrical constraints.
The system was tested on the tower of Cetara (SA) and will subsequently be tested on the rest of the Amalfitan Coast in order to evaluate how accurate it actually is as well as how *“real life”* the final product is.

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