

MAPPING OF ARCHAEOLOGICAL AREAS USING A LOW-COST UAV THE AUGUSTA BAGIENNORUM TEST SITE

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ABSTRACT

In the archaeological area of *Augusta Bagiennorum* different tests have been performed since 1990, in order to support the archaeological scientists using geomatics techniques. Photogrammetric aerial surveys (both helicopter and aircraft platforms were used) for large scale mapping, implementation of Geographic Information System devoted to archaeological investigations and Lidar surveys have been performed.

This archaeological scenario is an optimal test site to test the performances of the UAV prototype developed for ITHACA (Information Technology for Humanitarian Assistance, Cooperation and Action), a Centre of Excellence created by Politecnico di Torino (DITAG) and Si.T.I. (Istituto Superiore sui Sistemi Territoriali per l'Innovazione) to support the UN WFP (World Food Programme) activities. The main goal of the UAV project is to support disaster management through an innovative and effective tool for rapid mapping purposes in the early impact stage. The UAV is easily transportable on normal aircrafts and usable on the field, autonomously, by a couple of operators. The platform is equipped with the autopilot MP2128^g, which allows an autonomous flight except for take-off and landing, and with digital sensors characterised by geometric and radiometric resolutions suitable for digital photogrammetry.

The *Augusta Bagiennorum* archaeological area was surveyed using the Ricoh GR commercial digital camera. The camera was mounted on a pod mounted on the belly of the fuselage and allows to have a GSD (Ground Sample Distance) of about 75 mm, a 257 m side coverage and a shooting time interval of about 4,5 s flying at an altitude of 200 m with an average speed of 15 m/s.

The availability of stereo pairs allow to rapidly update existing maps, and to perform a 3D feature extraction devoted to the identification of areas that requires further investigations

The main objectives of the tests are:

- the evaluation of the 3D mapping accuracy in order to state the suitability for archaeological purposes;
- the analysis of the information content, in order to verify if the required map entities are easily recognisable on the images.

1. UAV SYSTEMS

UAV is the acronym of Unmanned Aerial Vehicle and refers to a class of aircrafts that can fly without the onboard presence of the pilot. They can be flown by an electronic equipment present on the vehicle and at a GCS (Ground Control Station), or directly from the ground. In this last case it is common to associate the system with the expression RPV (Remotely Piloted Vehicle), since the vehicle is remotely piloted and operated by radio-controlled devices. In literature other terms are adopted to indicate such category of vehicles, such as: Drone, ROA (Remotely Operated Aircraft), UVS (Unmanned Vehicle System). The development of UAVs started in the 50's for military purposes. During the cold war, different countries started projects with the aim of producing vehicles able to carry out missions with no onboard pilot. At present the market for UAVs has been rapidly growing in the military ambit. The constant increase of research programmes and the evolving technologies have allowed to implement systems able to fully satisfy the requested requirements.

The success in the military field offers a valid stimulus for the development of such systems for civil applications, especially in the field of environmental monitoring, agriculture and public security.

| UAV Categories | Acronym | Range (km) | Climb rate (m) | Endurance (hours) | Mass (kg) |
|--------------------------------|---------|------------|----------------|-------------------|-----------|
| Tactic | | | | | |
| Micro | (Micro) | < 10 | 250 | 1 | <5 |
| Mini | Mini | < 10 | 150 to 300 | < 2 | 150 |
| Close Range | CR | 10 a 30 | 3000 | 2 to 4 | 150 |
| Short Range | SR | 30 a 70 | 3000 | 3 to 6 | 200 |
| Medium Range | MR | 70 a 200 | 5000 | 6 to 10 | 1250 |
| Medium Range Endurance | MRE | > 500 | 8000 | 10 to 18 | 1250 |
| Low Altitude Deep Penetration | LADP | > 250 | 50 to 9000 | 0.5 to 1 | 350 |
| Low Altitude Long Endurance | LALE | > 500 | 3000 | >24 | < 30 |
| Medium Altitude Long Endurance | MALE | > 500 | 14000 | 24 to 48 | 1500 |

Table 1. UAV classification (UAV association)

The use of unmanned vehicles would ensure the possibility of carrying out long missions, without risking human losses and performing large-scale monitoring operations. UAV association classifies UAVs in three categories with respect to their

possible usage. Each typology of aerial vehicle is subdivided into subcategories, according to their features and performance; particular reference is made to the vehicle's range, maximum climb rate, endurance and weight. Depending on useable on the field and easy transportable needs, our attention is focused on the "tactical" group, in particular to the mini UAVs (table 1). Nowadays UAV-systems in photogrammetric applications are quickly increasing. The technological development of navigation systems allows the reduction of costs and the miniaturization of payloads. It is afterwards possible to set up projects based on "low cost" platforms.

2. THE UAV PROJECT

The UAV project is coordinated by ITHACA, with the main goal to carry on operational and research activities in the field of geomatics for analysis, evaluation and mitigation of natural and manmade hazards, in supporting the capacity of the UN WFP to prepare for and respond to humanitarian emergencies. Different projects are in progress, namely the creation of basic and thematic maps for emergency management in remote or flood-affected areas. If satellite data are not available or not suitable to supply radiometric and geometric information, in situ missions must be foreseen. To this purpose ITHACA has developed a "low cost" mini-UAV. "Pelican" is a remote-controlled aircraft equipped with a GPS/IMU navigation system and different photographic sensors suitable for digital photogrammetric shootings with satisfying geometric and radiometric quality. It can be easily transportable on normal aircrafts and useable on the field by a couple of operators.

2.1 The UAV prototype "Pelican"

The aerial platform is developed and patented by the department of Aerospace Engineering (DIASP) of the Politecnico di Torino. For a long time Proff. F. Quagliotti and G. Guglieri, have been engaged in planning and implementing mini-UAV for reconnaissance and monitoring civil applications. Since 2004, three prototypes have been made: "MicroHawk 600"; "MH 1000"; "MH 2000" (with reference to their wingspan in millimetres). Our attention turned to the bigger model, MH 2000, due to the payload requirements (about 1,5-2 kg). Hence, the commissioning for the realization of the prototype ITHACA 01 (Figure 1). The platform MH2000 is characterized by a conventional configuration: fixed wing, tailless integrated wing-fuselage, tractor propeller driven, all-electric power. The fixed-wing configuration gives the aerial vehicle a better capability of withstanding adverse weather conditions, such as gusts, and, besides, it allows larger payload capabilities and a superior flight performance.



Figure 1. The UAV prototype "Pelican"

The main technical features of the platform are synthesized in table 2

| SPECIFICATIONS | ITHACA 01 |
|--------------------------|-----------------------|
| WING SPAN | 2000 mm |
| Wing surface | 2.1 m ² |
| Length (fuselage) | 1750 mm |
| Width (fuselage) | 150 mm |
| Payload weight | 6,7 kg/m ² |
| Weight (body) | 10 kg |
| Max take-off weight | 14 kg |
| Payload | 2,5 kg (25%) |
| Lithium-ion batteries | 1,0 kg (10%) |
| Motor | 0,5 kg (5%) |
| Motor model | Hacker C50-21 XL |
| Output power | 2 hp @ 6600 rpm |
| Propeller | APC 16"x 8" |
| Min speed | 8 m/s (29 km/h) |
| Max speed | 20 m/s (72 km/h) |
| Optimum range limits | 25 Km |
| Optimum endurance limits | 1 h |

Table 2. ITHACA 01 technical specifications

2.2. Navigation system

The aircraft is equipped with the MP2128^g autopilot that allows autonomous flights and provides a real-time attitude of flight. The MP2128g is composed by an electronic circuit board and a ground control software (HORIZON^{mp}). The first component has a dimension of 100x40x15 mm³ with a weight of 28 g (Figure 2).

It includes a GPS unit, three-axis gyroscope and accelerometer (IMU), relative airspeed probe, pressure altitude transducer, AGL ultrasonic altitude sensor, and external servo board. The gyroscope, accelerometer, pressure altitude transducer and airspeed probe provide feedback at 5Hz, GPS has 1 Hz update rate. 2.4GHz radio modem allows to transmit the flight attitude to the Ground Control Station (GCS).

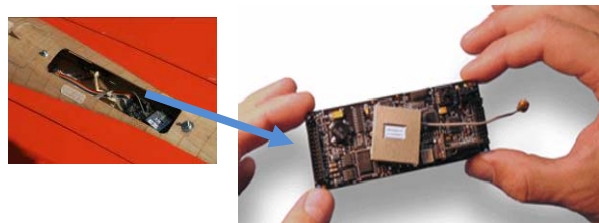


Figure 2. Autopilot position on the belly of the fuselage

The software HORIZON^{mp} provides flight path and current sensor values in real-time. The operator can also insert a flight plan (up to 1000 waypoints) on a preloaded map and upload them during the flight. Besides the system can be connected with the payload cameras, so it is possible to schedule an automatic shooting time. Therefore it is possible to carry out automated photogrammetric flights at half of the optimum range limits (within a range of about 25 km). The operations of take-off and landing must be accomplished manually due to the insufficient GPS's in-flight accuracy.

2.3. Sensors

The current configuration of the UAV allows to carry onboard digital sensors for video and imagery acquisition. The sensors are mounted in a pod (figure 3) placed on the belly of the fuselage, that can be remotely controlled through a 6 channels radio receiver. A real-time video downlink of the over-passed areas is made possible by the camcorder aimed at the digital camera display.



Figure 3. “Pod“ with Ricoh GR digital, and “pod” position under the UAV

At the moment the Pod is equipped with the semi-professional RICOCH GR camera (figure 4) characterised by a resolution of 8 Mpixel and a focal length of 5.9 mm. Its weight is only 200g (including battery and SD) and its dimensions (107 x 58 x 54 mm) allows to mount it in a “pod” with the long side of the format orthogonal to the fuselage axis. Furthermore at a flying altitude of 200 m and aircraft speed of 15 m/s it allow to have a GSD of 75 mm with a 257 m side coverage. The shooting time interval required for a 60% along-track overlap is about 4.5 s.



Figure 4. RICOCH GR digital

3. PHOTOGRAMMETRIC AERIAL SURVEY OVER THE ARCHAEOLOGICAL AREA

The ruins of the roman city of *Augusta Bagiennorum* are situated a few kilometres away from the actual city of Bene Vagienna (figure 5), on an agricultural level plane called “Piana della Roncaglia”. The zone is delimited by Mondalavia torrent (an affluent of Tanaro river) in the south-east part and by the hill that separate the plane from the Stura valley of Demonte in the north-west part. Due to the strategic position in the middle of Tanaro valley, *Augusta Bagiennorum* became an important centre exploited by the Roman for agricultural purposes and urban redevelopment. Since the II sec. a.C. *Augusta Bagiennorum* was one of the vertexes of a triangle, as the near cities *Pollentia* and *Alba Pompeia*, that were nodal points of the street network required for the empire expansion. Today the

archaeological evidences attest the presence of some public buildings such as the Theatre (figure 6) and the four-sided portico characterised by a central basement of a temple devoted to an unknown divinity. They are both located in the south-east part of the ancient city, the archaeological area in public view. Above the temple, preserved at foundation level, a little Christian Basilica was build, nowadays is possible to identify the perimeter walls with the major apse between two minor ones.

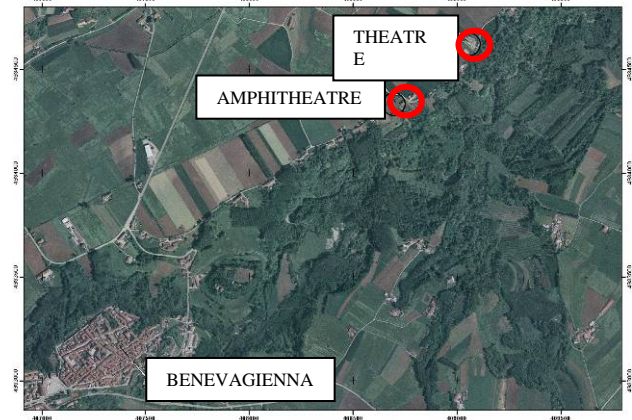


Figure 5. Bene Vagienna area (orthophoto, map scale 1:10,000)

The construction phases are referable at early Christian epoch (V-VI sec. d.C.) and high medieval period (VII-VIII d.C.). In front of the above described archaeological area some structures (houses or workshops) are well preserved, constitute by circular surroundings around a central court (I-II sec d.C.). Finally it is possible to recognise the Amphitheatre outside the old city (figure 6). In this area of the archaeological site the excavation works are still in progress. At the moment the works done by the municipality of Bene Vagienna are aimed to improve the management of the ancient site of *Augusta Bagiennorum* in cooperation with the archaeological superintendence of Piemonte.



Figure 6. Overview of the archaeological evidences: the Theatre (above) and the Amphitheatre (below)

3.1 Photogrammetric flight plans

Two different photogrammetric flights plans have been planned for both the Theatre and the Amphitheatre areas, that are: a low altitude flight (elevation of 60 m, GSD: 2 cm) and an high altitude one (elevation of 100 m, GSD: 4 cm).

At a flight altitude of 60 m using standard overlaps the theatre area is covered by a block of two strips with five frames (60% along track, 20% trasversal) while the amphitheatre site is

covered by a block of two strips with six frames (figure 7, above).

Setting the flying altitude at 100 m the theatre area is covered by a strip of four frames and the amphitheatre by one strip with five frames (figure 7, below).

Each photogrammetric flight plan has been designed setting the UAV speed at 15 m/s, which means a shooting time interval of about 1,5 s (60 m) and 2,5 s (100 m).

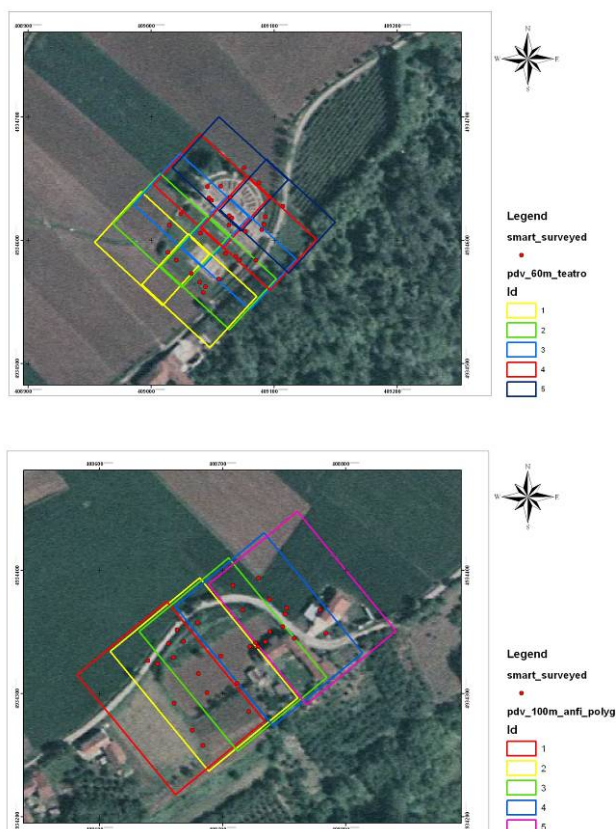


Figure 7. Flight plans and planned reference points pattern: the Theatre site (above) and the Amphitheatre site (below).

3.2 Reference point surveying

Topographic surveys have been performed in the two areas in order to materialize a network of reference point (RP) respect to WGS84-IGB00 datum (UTM projection).

The RP are represented by natural and man-made target points. The targets are 30x30 cm black and white square shaped (Figure 8). They have been built according to the results of several tests on the ground aimed at defining the optimal size, shape and colour.

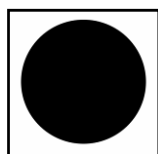


Figure 8. Man-made target for UAV photogrammetric resumption (30 cm x 30 cm)

The targets position has been planned according to the flight specification and the accessibility of the surroundings of the archaeological sites. The stake off operations (figure 9) have been carried out with GPS Leica RX1200 receiver in RTK multi reference station mode.

Natural points have been surveyed with Leica SmartStation. This instrument allows to combine TPS measurements and GPS observations in RTK mode. Therefore it is possible to carry out detailed survey without control points or traverses. The coordinate of points in the reference system (UTM WGS84 IGB00) are available in real time.

The detailed survey has been focused on inaccessible points like roof or wall corners in order to obtain a RP network with suitable elevation range.



Figure 9. Topographic survey in the Amphitheatre area

The average accuracy of points is 0.04 m, suitable for the aim of the project. The number of RP is resumed in table 3.

| | Anphitheatre | Theatre |
|-----------------------|--------------|-----------|
| Natural points | 12 | 12 |
| Target points | 20 | 16 |
| Total | 32 | 28 |

Table 3. number of points surveyed

3.3 Images acquisition

The UAV was remotely driven by a pilot on the ground, due to some problems with the autopilot in following a straight line. Anyway the presence of the autopilot allowed position and attitude data to be logged for post-processing purposes and for real-time monitoring. Flight parameters such as position, pitch, roll and yaw (Figure 12) can be further processed for a possible direct-georeferencing approach.

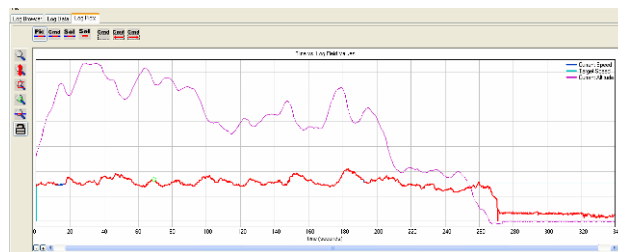


Figure 10. Speed and elevation plots.

The link between the digital camera and the autopilot allowed to acquire frames automatically. Shooting time interval was set equal to 2 seconds through the GCS HORIZON^{mp} software. Images acquisition automatically started at a flying altitude of 25 m.

3.4 Image processing

Two different triangulation tests have been performed using the Leica Photogrammetric Suite software. Image processing in LPS has been carried out according to the following scheme:

- Ground Control Points measure (manually);
- Check Points measure (manually);
- Tie points measure (automatic);
- Bundle block adjustment.

The internal orientation parameters (focal length, coordinate of principal point and radial lens distortion) of the RICOH GR camera have been estimated during the Bundle adjustment following a self-calibration approach. An a priori estimation was performed using a self-developed calibration software, but it was found a non stability of the radial distortion parameters. This is probably due to the fact that the lens is retractable, that means it move in and out during switching on/off operations. For this reason it will be build a new pod for a professional SLR digital camera such as the Canon Eos 5D.

For the first test three frames acquired over the theatre and coming from different strips have been processed (Figure 11).

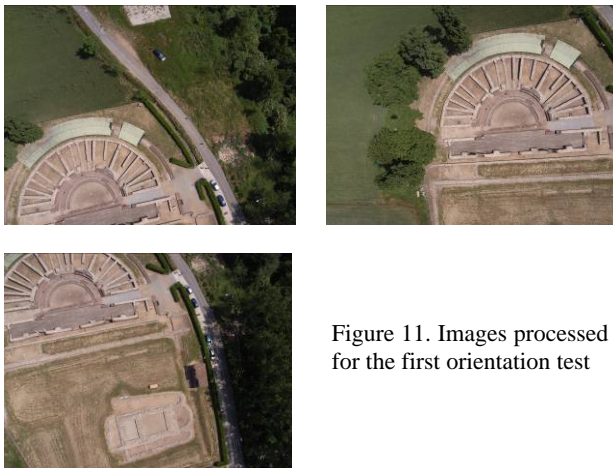


Figure 11. Images processed for the first orientation test

Figure 12 shows the position of the 7 ground control points and the 3 check points used in the bundle adjustment process.

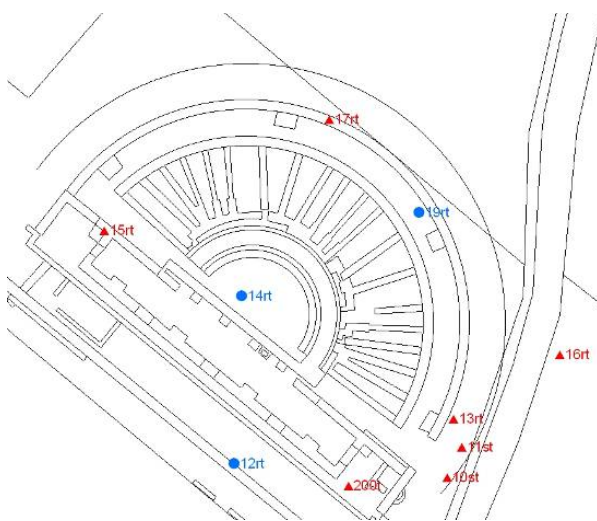


Figure 12. Theatre Ground control Points (red triangle) and Check Points (blue circle)

The results of the triangulation are in the tables 4 and 5. The achieved accuracy is the expected one and suitable for the goal of the project.

| Point ID | D _x | D _y | D _z |
|-----------------|----------------|----------------|----------------|
| 200 | -0.02 | 0.00 | 0.01 |
| 10st | 0.08 | 0.04 | 0.00 |
| 11st | 0.03 | -0.01 | -0.07 |
| 13rt | -0.04 | 0.02 | 0.09 |
| 15rt | -0.04 | 0.06 | -0.02 |
| 16rt | -0.01 | -0.03 | -0.01 |
| 17rt | 0.00 | -0.07 | 0.00 |
| Mean | 0.00 | 0.00 | 0.00 |
| Mean Abs | 0.03 | 0.03 | 0.03 |
| Sqm | 0.04 | 0.04 | 0.05 |

Table 4. GCP residuals

| Point ID | D _x | D _y | D _z |
|-----------------|----------------|----------------|----------------|
| 14rt | -0.04 | 0.03 | -0.13 |
| 12rt | -0.09 | -0.01 | 0.03 |
| 19rt | -0.03 | 0.00 | -0.08 |
| Mean | -0.05 | 0.01 | -0.06 |
| Mean Abs | 0.05 | 0.02 | 0.08 |
| Sqm | 0.03 | 0.02 | 0.08 |

Table 5. CP residuals

The second orientation test has been performed on the Amphitheatre area, using 4 frames acquired at a flight elevation of 100 m (Figure 13).



Figure 13. Images utilized for the triangulation process

In the triangulation process 13 ground control points and 8 check points have been used: the GCPs and CPs position of is shows in figure 15.

A comparison between high altitude and low altitude frames (figure 17) shows that an higher height allow the pilot to better control the UAV speed and to follow a straight line. On the other hand low altitude images are more detailed, allowing an improvement of the accuracy during the 3D feature extraction. The expected improvements in the autopilot performances, that means a better capability of following a predefined flight plan, will allow to fix the before described problems.

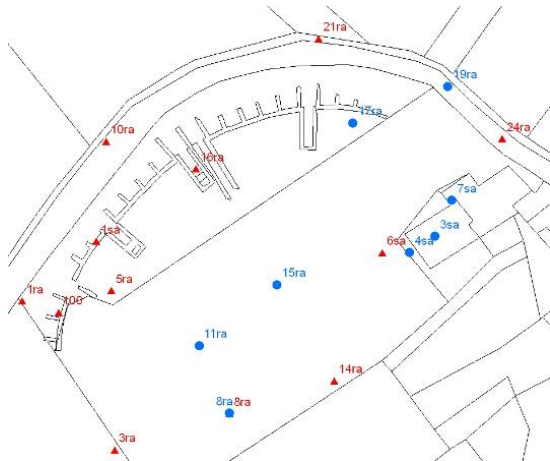


Figure 14. Amphitheatre Ground control Points (red triangle) and Check Points (blue circle)

Tables 6 and 7 highlights the residual of GCPs and CPs.

| Point ID | D _X | D _Y | D _Z |
|-----------------|----------------|----------------|----------------|
| 100 | 0.06 | -0.02 | 0.01 |
| 1sa | -0.05 | -0.01 | -0.01 |
| 6sa | 0.03 | 0.00 | 0.01 |
| 1ra | -0.02 | 0.00 | 0.01 |
| 3ra | -0.02 | 0.04 | 0.00 |
| 5ra | 0.00 | 0.00 | 0.00 |
| 8ra | 0.01 | 0.00 | 0.00 |
| 10ra | -0.02 | 0.00 | 0.00 |
| 14ra | 0.00 | 0.01 | 0.01 |
| 16ra | 0.01 | 0.00 | -0.04 |
| 21ra | 0.03 | -0.01 | 0.04 |
| 23ra | 0.00 | 0.05 | -0.01 |
| 24ra | -0.03 | -0.05 | -0.01 |
| Mean | 0.00 | -0.01 | 0.01 |
| Mean Abs | 0.06 | 0.06 | 0.06 |
| Sqm | 0.03 | 0.05 | 0.03 |

Table 6. GCP residuals

| Point ID | D _X | D _Y | D _Z |
|-----------------|----------------|----------------|----------------|
| 7sa | 0.10 | -0.07 | -0.16 |
| 15ra | -0.01 | -0.02 | 0.05 |
| 4sa | -0.01 | 0.09 | 0.02 |
| 17ra | 0.01 | -0.02 | -0.04 |
| 19ra | 0.08 | -0.05 | 0.03 |
| 8ra | 0.00 | 0.02 | -0.09 |
| 3sa | 0.01 | -0.03 | -0.08 |
| 11ra | 0.00 | 0.02 | 0.05 |
| Mean | 0.00 | 0.00 | -0.04 |
| Mean Abs | 0.01 | 0.00 | -0.01 |
| Sqm | 0.01 | 0.03 | 0.08 |

Table 7. CP residuals

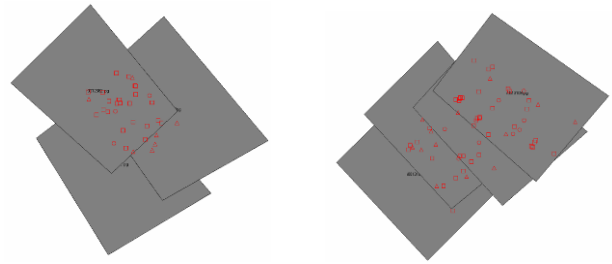


Figure 17. Processed frames: low altitude (left) and high altitude (right)

4. CONCLUSIONS AND FUTURE WORKS.

The UAV prototype “Pelican” was used to test the capability to perform a photogrammetric survey for archaeological purposes. The obtained 3D accuracy is suitable for archaeological evidences mapping at a very large map scale.

At the moment the photogrammetric test is still in progress: the aim is to perform a larger triangulation using several frames for DSM extraction and orthoimages production tests. A planned development of the UAV project is to process the position and attitude data logged by the autopilot during the flight, in order to estimate the 3D accuracy achievable through a direct georeferencing approach.

The research group is already collaborating with the Aerospace Department of Politecnico di Torino in order to fix the navigation issues, mainly related to the capability of the UAV to perform autonomously flights following the predefined flight-plan.

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