POLITECNICO
MILANO 1863

# LOW-COST DGPS ASSISTED AERIAL TRIANGULATION FOR SUB-DECIMETRIC ACCURACY IN UAV PHOTOGRAMMETRY

Francesco Ioli[1]
[1] Department of Civil and Environmental Engineering (DICA), Politecnico di Milano, francesco.ioli@polimi.it

## 1 Goal of the study

The goal of the study is to develop a low-cost system to perform UAV-based photogrammetry with GNSS Assisted Aerial Triangulation (AAT) in order to reduce the number of Ground Control Points traditionally required to achieve high geometrical accuracy of photogrammetric blocks. This can be achieved by mounting lightweight and low-cost GNSS receiver mounted on-board the UAV. The synchronization between the camera shooting time and the GNSS time is obtained by means of a marker recorded in the UAV flight log at each shot, rather with hardware connection with the camera which is usually troublesome when dealing with off-the-shelfs commercial UAVs camera.

The aim is to achieve at least a 10-15 cm accuracy in deteriming the coordinates of the camera prospective centres during each shot. According to the simulations, this may lead to a reprojection accuracy on ground ranging from 3 to 7 cm, depending on the numbers of GCPs used (at leat one) and the acquisition geometry.

## 2 Instruments and methods

For the study, a commercial UAV Matrice 210 V2 is equipped with a DJI Zenmuse X5S camera with a 4/3" sensor and a DJI MFT 15mm/1.7 ASPH lens, mounted on a 3-axis gimbal. A compact single frequency GNSS receiver Emlid Reach M (less than 200 €) with a patch antenna is installed on the UAV (Fig.1).

Raw GNSS observations recordered at a frequency of 5 Hz during the flight are processed in PPK by using RTKlib in order to obtain the UAV trajectory (Fig. 2).

Either an in-situ base station or a permanent one (~20 km away) are used and the phase ambiguity is fixed with a Fix and Hold approach.

Shooting times are taken from the telemetry data, recorded with a sample rate of 200 Hz inside the drone flight logs during autonomous flights controlled by UgCS software. From shooting times and trajectory of the antenna, it is possible to interpolate the antenna's coordinates at each shooting position. Considering the attitude of the drone, recorded in the telemetry, it is possible to obtain the coordinates of the camera perspective centers.

**Fig. 1:** The DJI Matrice 210 V2 with a Zenmuse X5S camera and the Emlid Reach M GNSS receiver mounted on the drone.

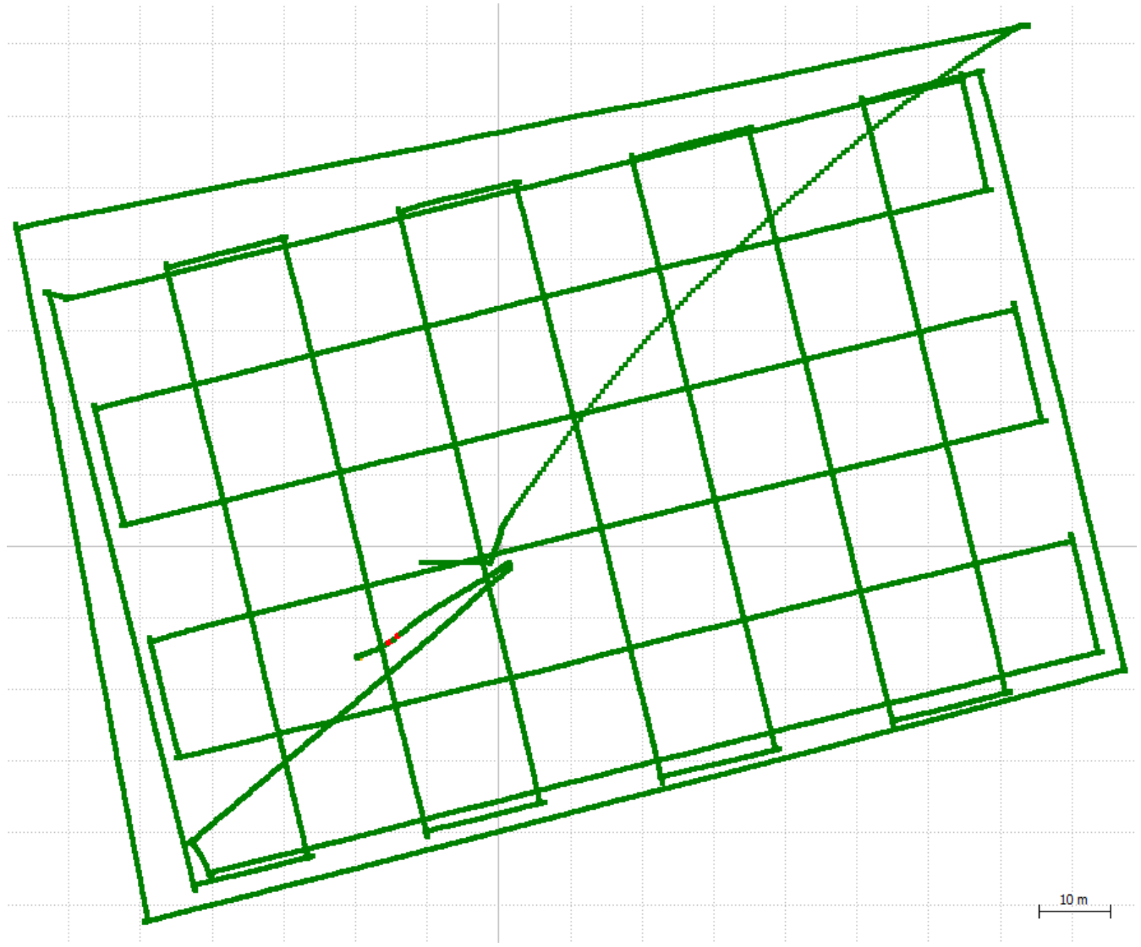

**Fig. 2:** A PPK post-processed GNSS trajectory. Green dots means that the ambiguity is fixed.

## 3 System calibration

### 3.1 Camera calibration

The calibration of camera Internal Orientation (IO) was performed by solving a strongly constrained block with 12 GPCs measured with a sub-centimetric precision with a total station Leica MS60, and always seen in 43 images (Fig. 3).

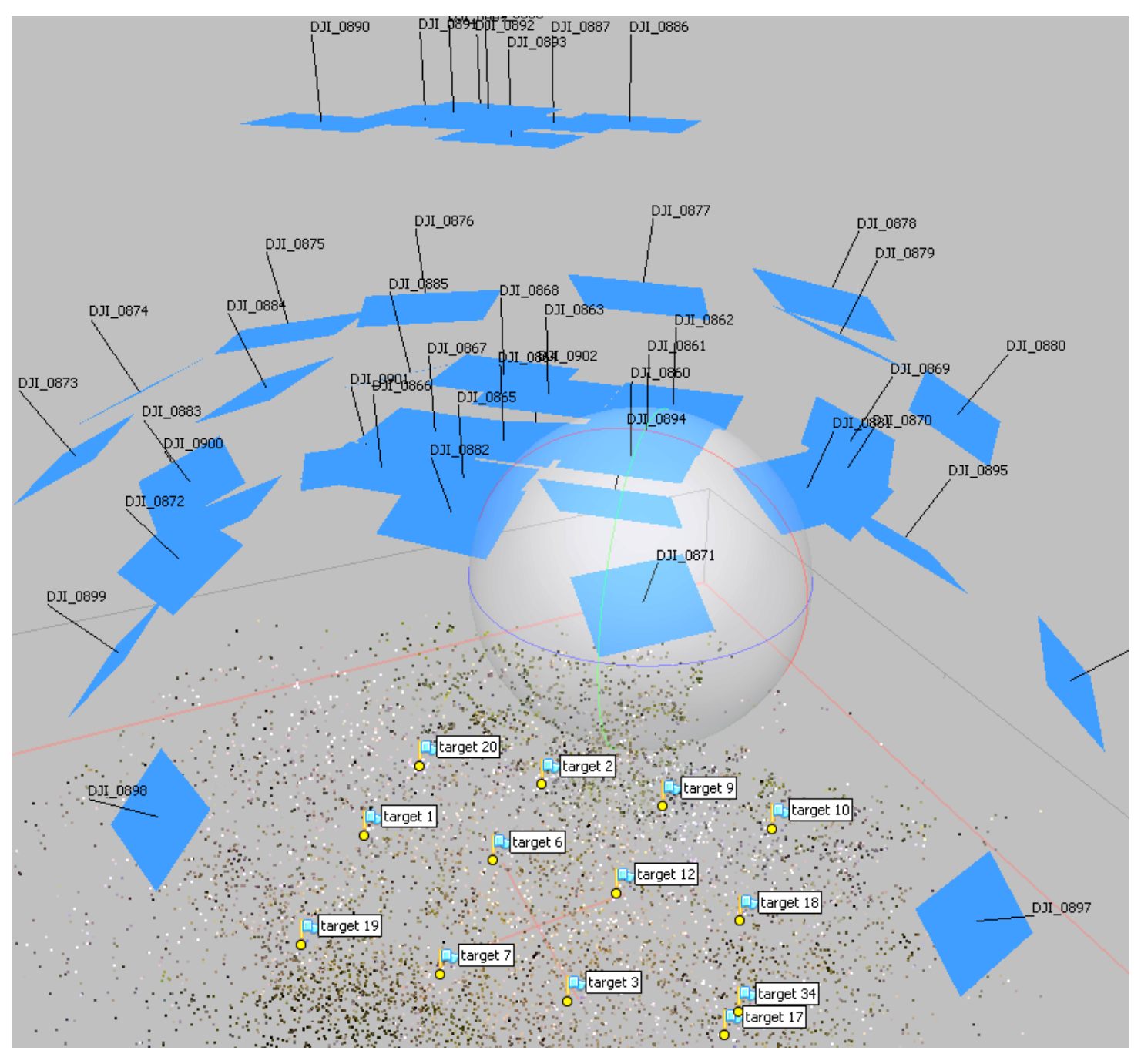

**Fig. 3:** Camera calibration block.

### 3.2 Camera-antenna vector calibration

The offset vector was calibrated first in the Camera Levelled Reference System (i.e. with the camera looking nadiral and with the top of the camera looking front towards the UAV nose, Fig. 4) by estimating the center of projections of 7 nadiral photos with a photogrammetric block measuring the antenna phase center with PPK (averaging ~30 s of observation for each photo). By means of the drone attitude angles (roll, pitch and yaw), the vector in the Camera Levelled was rotated in a body-fixed reference system (Body RS, Fig. 4). The result of the calibration is presented in Tab. 1a. Assuming the rotation center of the gimbal as the camera perspective center (the lens is small and the aimed precision is in the order of the centimeter), the calibrated vector was used to estimate the camera coordinates of additional 14 images taken with different drone attitudes and gimbal orientation w.r.t. the drone itself. These were compared with the camera perspective centers obtained from a photogrammetric block with centimetric errors (Tab. 1b).

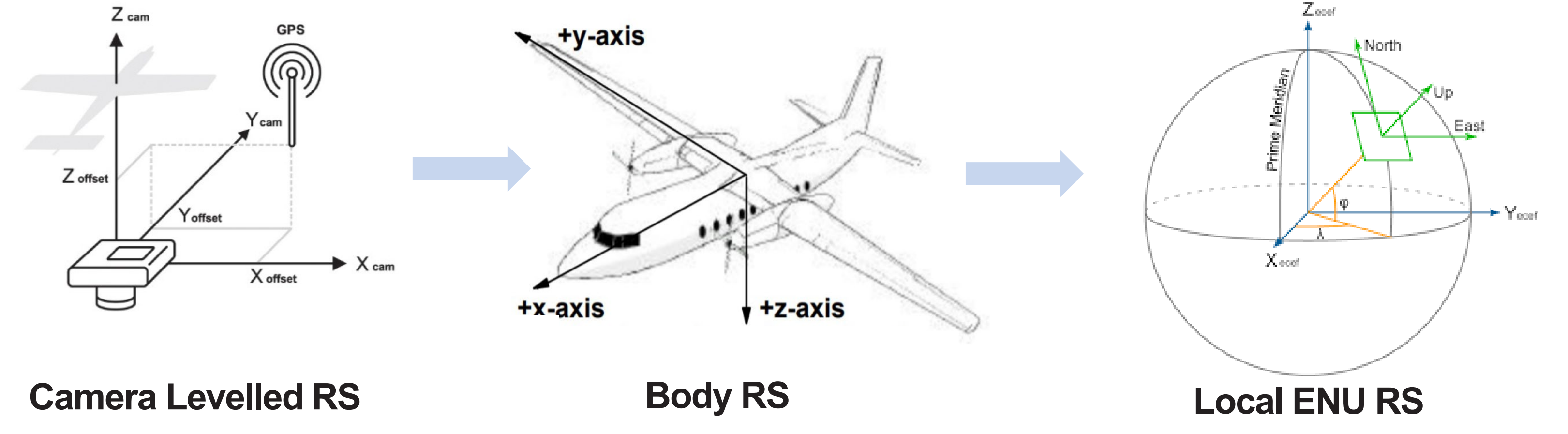

**Fig. 4:** The reference systems used to calibrate the camera-antenna offset vector.

| | Calibrated vector in Body RS | | | Validation in the local ENU RS | | |
|---|---|---|---|---|---|---|
| | x | y | z | E | N | U |
| Mean [m] : | -0.130 | -0.064 | -0.350 | -0.016 | -0.010 | -0.006 |
| St.Dev [m] : | 0.002 | 0.002 | 0.001 | 0.014 | 0.014 | 0.007 |
| | (a) | | | (b) | | |

**Tab. 1:** Result of the camera-antenna vector calibration (a) and the differences between the estimated values of the camera centers (i.e. GNSS antenna + vector) and the photogrammetric solution (b).

### 3.3 Synchronization between shot markers in telemetry and actual shooting time

The delay between the actual mid-exposure time of each shot and the time in which the "Succeed Shot" mark is registered in the telemetry log must be also calibrated. This was done by estimating a temporal offset along the trajectory in order to minimize the differences between the camera coordinates estimated interpolating the GNSS trajectory (properly corrected with the camera-antenna vector) and those obtained with a traditional photogrammetric block (Fig. 5). After having estimated a temporal offset of 0.43 ± 0.04 s, RMSE of the differences equal to 0.09 m, 0.11 m and 0.03 m were obtained respectively in E, N and U directions (Fig. 6).

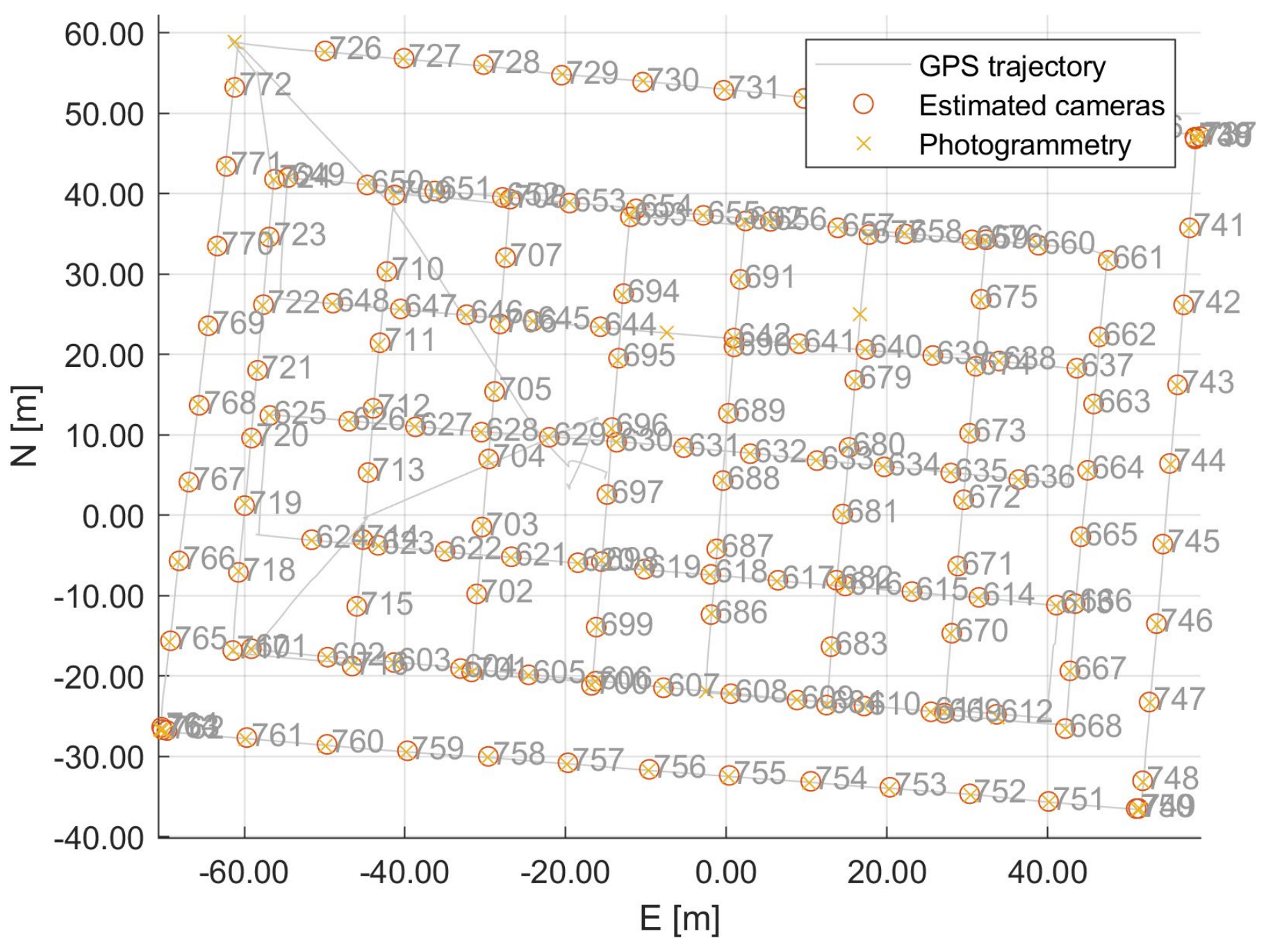

**Fig. 5:** Photogrammetric block used for the temporal offset calibration.

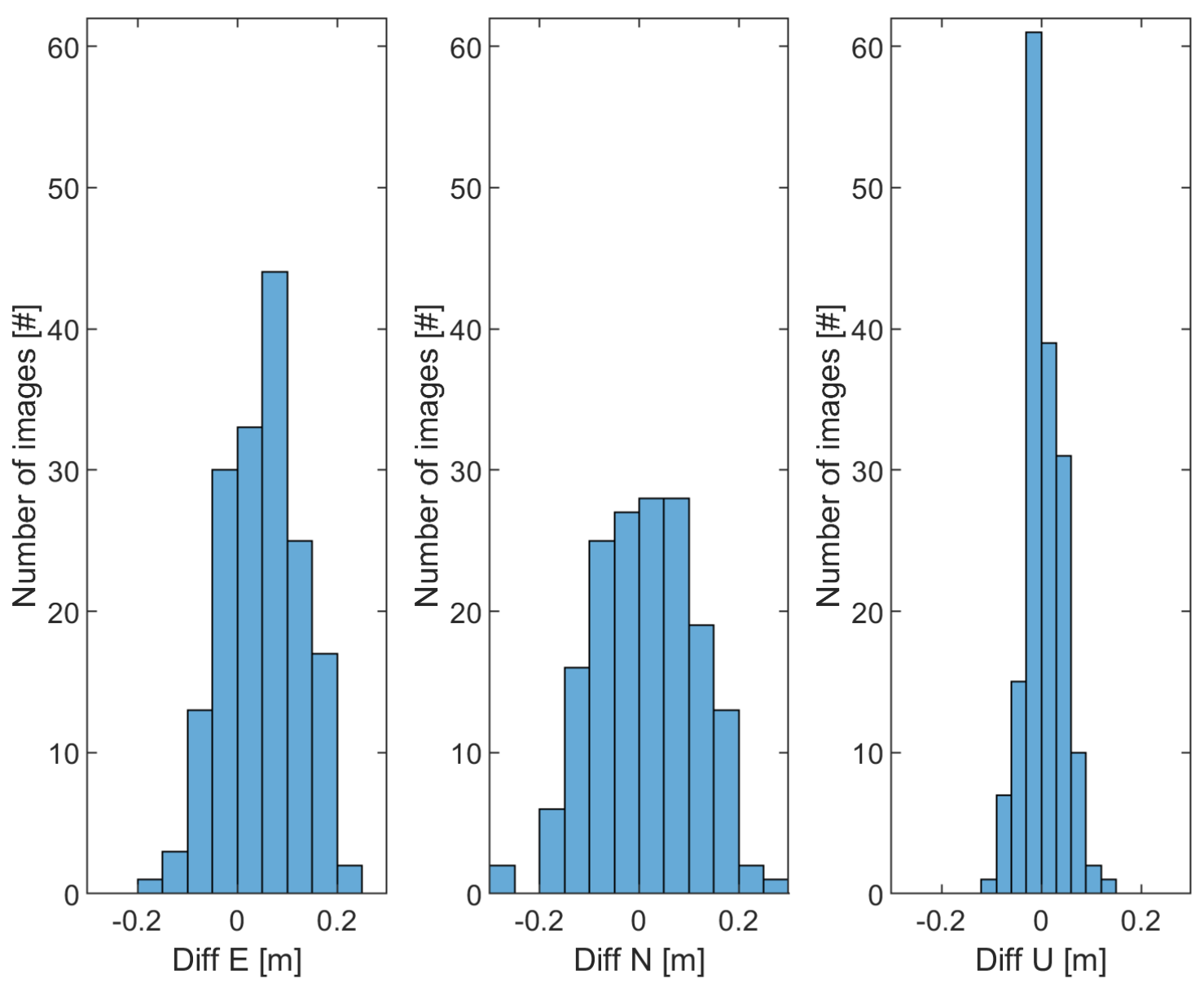

**Fig. 6:** Absolute frequencies of the differences between the estimated camera coordinates and those obtained by a traditional photogrammetric block.

## 4 Results of AAT on an indipendent block

In order to test the proposed method, an independent flight was carried out. A set of 13 GCPs were materialized on an area of ~10 ha and measured with a total station MS60 with sub-centimetric accuracy. The coordinates of each camera were estimated interpolating the GNSS trajectory at the time marked by the "Succeded Shot" event mark in the telemetry plus 0.43 s of temporal offset and summing the camera-antenna vector, properly rotated into the local ENU RS on the basis on the UAV attitude.

**Fig. 7:** Survey area of the test site. Blue flags are the GCPs and white dots are the positions of all the camera in the photogrammetric blocks.

Different acquisition geometry was tested . Moreover, a different number of GCPs was used to constrain the block. The results, in terms of on-ground reprojection, were evaluated on the remaining Check Points (CP) not used to solve the Bundle Block Adjustment and are presented in Tab. 2. As expected, the best result was obtained by using 3 GCPs and a very robust acquisition geometry. This is almost comparable to the result obtained with the traditional photogrammetric block. However, even using 1 single GCP, but a good acquisition geometry, it is possible to achieve an RMSE of 4-5 cm on ground.

| Acquisition Geometry | GCPs and CPs | Overlap | E [m] | N [m] | U [m] | RMSE [m] |
|---|---|---|---|---|---|---|
| Grid acquisition | 3 GCP, 10 CP | Long: 70%, trans: 60% | 0.006 | 0.006 | 0.007 | 0.011 |
| Grid acquisition | 1 GCP, 12 CP | Long: 70%, trans: 60% | 0.039 | 0.030 | 0.034 | 0.060 |
| 6 E-W stripes only | 1 GCP, 12 CP | Long: 70%, trans: 60% | 0.033 | 0.033 | 0.009 | 0.048 |
| 3 E-W stripes only | 1 GCP, 12 CP | Long: 70%, trans: 20% | 0.027 | 0.084 | 0.029 | 0.094 |
| 3 E-W stripes with 2 transversal stripes only | 1 GCP, 12 CP | Long: 70%, trans: 20% | 0.029 | 0.031 | 0.032 | 0.053 |
| Grid acquisition; traditional photogrammetry (TAA) | 9 GCP, 4 CP | Long: 70%, trans: 60% | 0.003 | 0.005 | 0.007 | 0.009 |

**Tab. 2:** Result of the TAA with different acquisition geometry and different number of GCPs. All the results are computed as on-ground reprojection error on the basis of the CPs only.

## 5 Conclusive remarks

This work highlights the possibility to perform AAT by mounting a low-cost GNSS receiver on-board a UAV, even without a hardware connection with the camera, to achieve sub-decimetric accuracy on ground and limiting the number of GCPs required. The test confirms the simulation results: according to those, an accuracy of ~10-15 cm in the camera coordinates can be good enough to obtain a RMSE between 1 and 6 cm on ground, provided a good acquisition geometry and at least a good GCP (that is particularly required to constrain the estimation of the focal length).