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UAS-LC-GNSS: Precision Surveying with a Low-Cost GNSS System for Commercial Drones

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Short note

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ABSTRACT

INGV (National Institute of Geophysics and Volcanology, Italy) is one of the institutions that studies and monitors the geophysical phenomena (earthquakes, volcanic eruptions, landslides, etc.) that occur on Earth. During these events, it is essential to carry out a large, detailed and fast map of the affected areas.
If we think of the difficulties encountered during the mapping of the fault sources for the 2016 earthquake in central Italy, we can understand how the UAS (Unmanned Aircraft System) can be a valid "low-cost" alternative to the traditional methods of surveys.
These devices, thanks to precision instrumentation such as GNSS (Global Navigation Satellite Systems) receivers and IMU (Inertial Measurement Unit) control units, allow a detailed reconstruction of the investigated areas, especially for small-scale analysis applications. These aircraft are based on multiple technologies and show great investigative capabilities, therefore they must be considered as complete systems.
Starting from these concepts, we have developed a low-cost RTK/PPK (Real Time Kinematic/Post Processing Kinematic) GNSS survey system on "commercial" UAVs (Unmanned Aerial Vehicles), i.e. professional drones that are not created to be modified.
We have demonstrated how the integration of a GNSS RTK/PPK module on commercial UAVs makes the system efficient for the reconstruction of a highly detailed and precise DEM (Digital Elevation Model), without using GCP (Ground Control Point), allowing to make precision measurements in areas that are difficult to explore and investigate. Indeed, the altimetric trends of the PPK processing without GCPs are perfectly comparable with those of the PVs (Verification Points) deriving from RTK analysis and sshow small acceptable deviations. The height differences between PVs measurements and those deriving from the DEM in the same planar coordinates vary between a minimum of 1 cm and a maximum of 7.8 cm. Based on these results, we can state that the precision mapping with a drone equipped with an on-board GNSS module does not differ much from the technique that involves measuring GCP on the ground, in reality, it is comparable in terms of errors, even on the more difficult field of altitudes.

KEY-WORDS: UAS , RTK-PPK , precision surveying , GNSS , GCPs.

INTRODUCTION

For remote sensing surveys, different sensors are used (camera, laser, radar, etc.) installed on different platforms (satellites, planes, drones, etc.). One of the parameters that influences the resolution in the results is the flight altitude of the platform (Bandopadhyay et al., 2020).

Nowadays the use of APR (Aircraft Piloted Remotely) also known as drones is increasingly widespread. These systems are also known as micro and mini UAV (Unmanned Aerial Vehicle) or also as UAS (Unmanned Aircraft System). The latter indicates the entire system consisting of the aircraft/platform (UAV) and the GCS (Ground Control Station) (Granshaw, 2018).

The first geomatics surveying experiences were conducted about 50 years ago (Bédard, 2007). Only recently has it become a common survey technique, thanks to the technological development of platforms, sensors, GNSS/IMU positioning systems, which allow immediate georeferencing.

UAS is mainly used to carry out detailed photogrammetric surveys (Rossi et al. 2019; Regmi et al. 2020) in the architectural, archaeological and environmental fields, but also for surveys with multispectral cameras for investigations in the agricultural field.

The main advantages of this technology are (Devoto et al., 2020):

- speed in carrying out the survey;
- ability to map areas that are difficult to access;
- higher image resolution than that obtainable from "traditional" aerial photogrammetry;
- contained costs of the acquisition phases.

The purpose of this project is to implement a low-cost RTK/PPK GNSS system on board a commercial and non-customizable drone. With this approach it is possible to georeference the images directly on board, avoiding the post processing. (Famiglietti et al., 2021).

After different tests and analysis of the esults, has been shown that it is possible to replace the "classic method" of surveying via UAV platform, thath use of GCPs (Ground Control Points), with a more immediate and less expensive scanning method based on direct "geotag" on board the drone (McMahon et al., 2021; Bayanlou & Khoshboresh-Masouleh, 2021).

MATERIAL AND METHODS

The drone used in this project is a multirotor (Yan & Chunlu, 2018), DJI Phantom 4 Pro; the same system was also tested on the previous model, the DJI Phantom 3 Pro. Stereo vision sensors are installed on the front and back, infrared sensors on the left and right, and ultrasonic sensors on the bottom. This sensor system allows it to detect obstacles in 5 directions.

A complete system for GNSS data acquisition connected to the camera shutter trigger has been implemented on the drone, shown in figure 1. The system is self-powered and does not affect the performance and flight duration of the UAV.

The connection of the GNSS Receiver to the camera, which allows us to synchronize a "geotag" on the image every time the camera triggers a shot (Božić-Štulić et al., 2017; Štroner et al., 2020), took place via the system shown above which connects the Phantom 4 Pro's camera flash pin with the PWM output of the GNSS module. The system includes two other intermediate elements that make the camera communicate with the GNSS receiver, as shown in figure 1:

1) *P4 Pro camera:* the camera of the drone was put in communication with the PPK (Post Processing kinematic) system with direct connection to the pulse of the LED associated with it. Every time a photo is taken, an electrical impulse is sent to the installed system;
2) *Voltage Regulator:* DC-DC Step Down Buck Voltage Converter/ Regulator, is used to lower the voltage threshold from 15 V to 2.2 V and to stabilize it.
3) *Microcontroller Arduino Nano:* It is a small sized card using an ATMEGA328 processor which has 32kB of program memory. It has 14 digital inputs/outputs (of which 6 can be used as PWM outputs), 8 analog inputs and a 16 MHz oscillator. The camera is connected to a PWM Pin of the microcontroller. A script in C language has been implemented, to interface Arduino with the camera through the mentioned Pin.

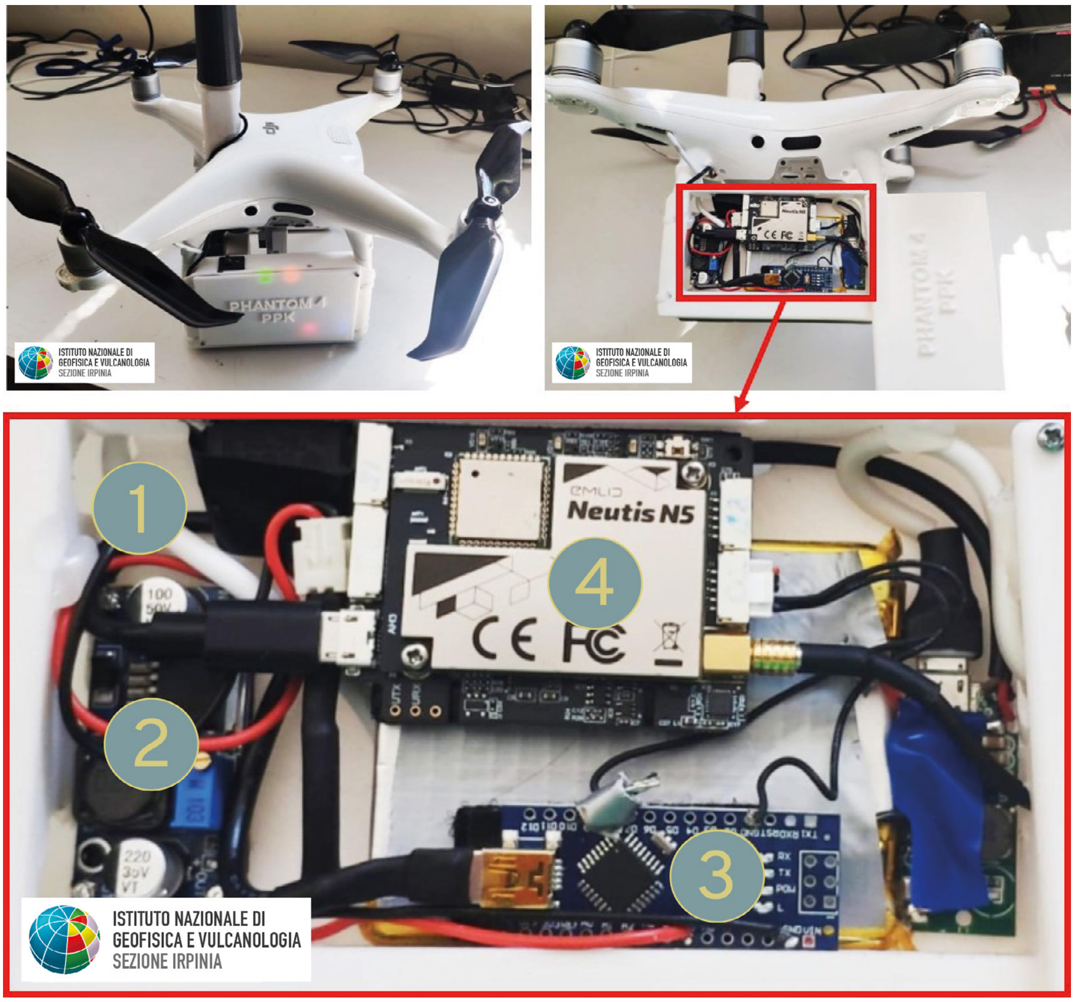

Fig. 1 - DJI Phantom 4 with PPK system.

4) *GNSS receiver:* A low cost and small size multiband and multi constellation GNSS receiver of the Emlid Reach M2 type, with the following main features: Antenna DC bias 3.3V; Static position accuracy horizontal/vertical 4 mm + 0.5 ppm/8 mm + 1 ppm; kinematics position Accuracy Horizontal/Vertical 7mm + 1ppm/14mm + 1ppm; Data type: NTRIP correction, VRS, RTCM3, NMEA output position, LLH/XYZ; RINEX data logging with frequency up to 10 Hz; GNSS Signal tracked: GPS/QZSS L1C/A, L2C, GLONASS L1OF, L2OF BeiDou B1I, B2I, Galileo E1- B/C, E5b, 184 channels with Update rates 20 Hz* GPS / 10 Hz GNSS type IMU9DOF.

The setting of the GNSS module is done both via the app and via the Web Interface in hotspot or client mode:

In the Camera control section, we have the possibility to choose how to set the trigger associated with the camera shot:

- in the “Fixed period” mode, one position is stored every Δt selected;
- in “Trigger events” mode, the impulse that comes from the camera automatically “marks” a position on the GNSS receiver.

In the RTK setting section both the mode and the acquisition parameters are set. It is possible to choose the position correction mode (in our case in Kinematic), with which Cut-OFF angle (Elevation mask angle) and with which noise mask (SNR mask). We can also enable the satellite constellations (GNSS select) to be used and the data sampling frequency (update rate).

In the Logging section, the data logging method is chosen. The receiver has been set to store RAW data in UBX format (Ublox proprietary format). Furthermore, it is also possible to store the positions and corrections of the base if working in differential mode.

In this project the processing methodology used for the correction of the GNSS data was PPK (Post Processing Kinematic), which allows to acquire the raw data of the Rover on UAV (Rover log) and of a base (Base log), and process them subsequently.

The system test was done at the INGV Irpinia section of Grottaminarda (AV). A photogrammetric mission was planned with a flight speed of 5 m/s, GSD (Ground Sampling Distance) to 2 cm, Overlap 80% and Sidelap 70%, with a double grid scheme, using the UGCS professional software in the Pro version and the specific Photogrammetry tool.

The station GRO1 belonging to the RING (RETE INTEGRATA NAZIONALE GNSS, http://ring.gm.ingv.it) of INGV was used as a base for the PPK. The data was acquired with the same sampling frequency of the UAS (10Hz).

Thirty verification points (PVs) were measured with multi-constellation and multi-frequency GNSS instrumentation. The points position was calculated in NRTK mode, with real-time correction using INGV’s NTRIP Caster using the GRO1 station as mountpoint.

Using the REDtoolbox software (https://www.redcatch.at/redtoolbox/), the PPK of the GNSS data of the base (GRO1) was elaborated and associated the relative positions to the photos taken, producing a dedicated project (.psx) for the photogrammetry software Agisoft Metashape PRO (https://www.agisoft.com/features/professional-edition/). As a result of that processing, the complete report containing three color-coded maps was obtained.

The color map used is green yellow and red where:

- Green indicates FIX solutions;
- Yellow indicates FLOAT solutions;
- Red indicates any other solution.

The “Path Map” (figure 2A) contains a color-coded map of the rover’s path.

The “Trigger Map” (figure 2B) contains a color-coded map of the triggers and their positions relative to the rover’s path. Each trigger point is color-coded according to the above classification (the “first” trigger is indicated with a triangle).

The “Height Map Path” (figure 2C) contains a diagram showing the height of each trigger, where each point is color coded according to the previous classification.

RESULTS AND CONCLUSION

Subsequently to the PPK processing of the GNSS data and after associating the correct positions to the images, we proceeded to the photogrammetric processing with the production of:

- Dense Point Clous.
- DEM (Digital Elevation Model).
- Orthomosaic.

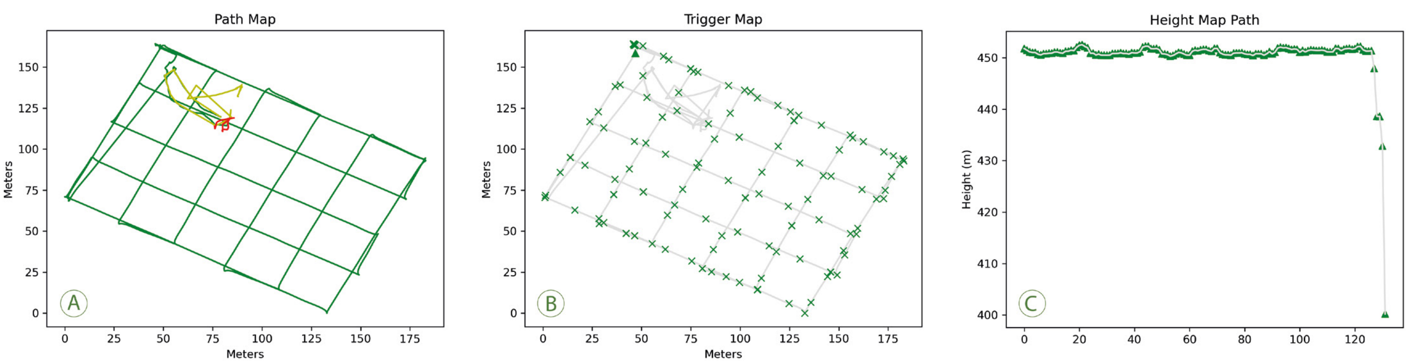

Fig. 2 - (A) Drone route map; (B) Trigger map/drone path; (C) Drone height/trigger map.

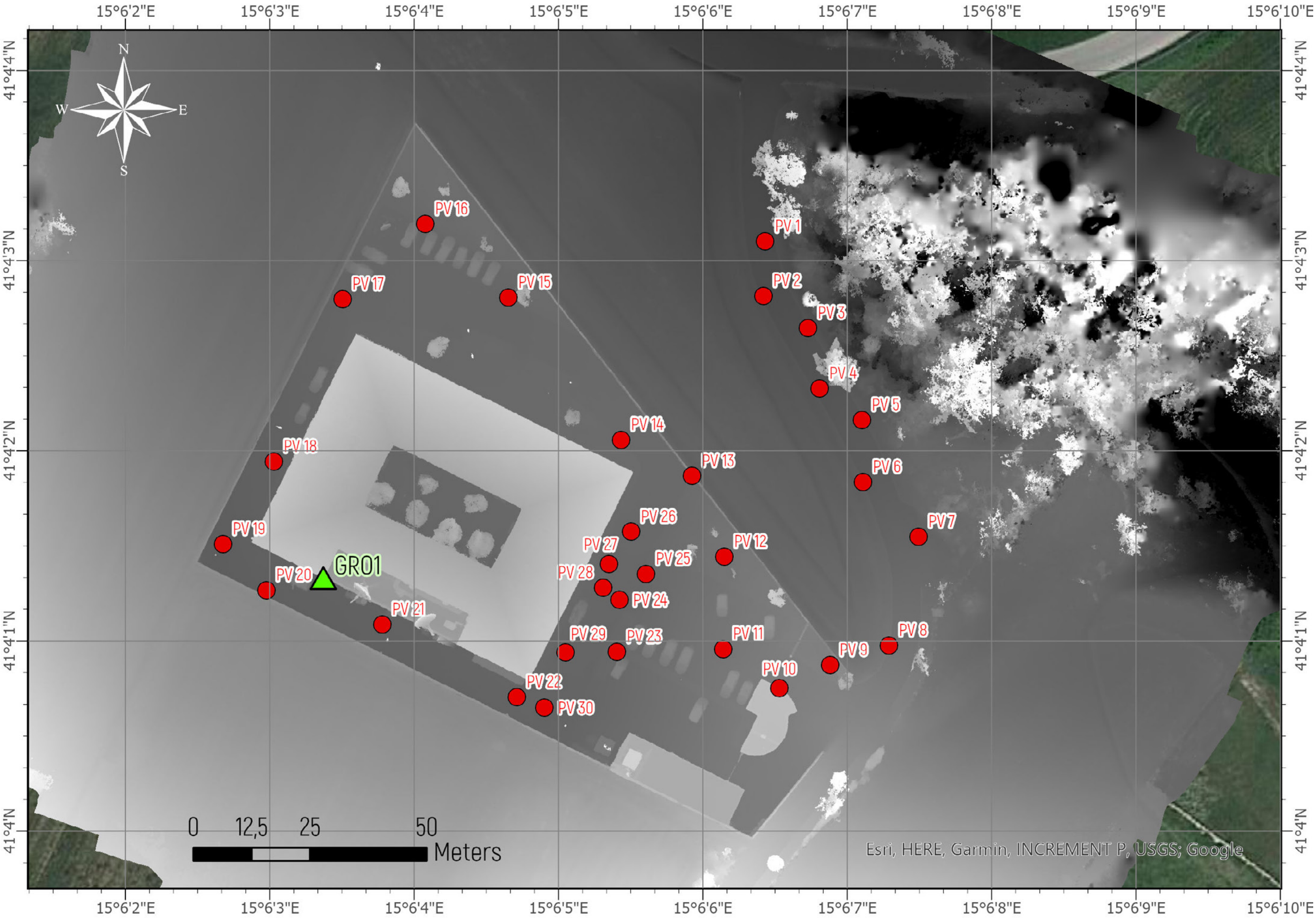

Fig. 3 - DEM/PVs comparison in GIS.

The accuracy of the results obtained have been verified by analyzing the DEM (Digital Elevation Model) produced in a GIS environment, comparing it with the precision measurements carried out on the PVs.

All layers have been georeferenced in the same reference system, WGS 84 / UTM zone 33N - EPSG:32633.

From the comparison of the altimetric measurements of the DEM produced and the measured PVs, the situation summarized in table 1 and figure 4 was obtained.

As shown in the figure 4, the altimetric trends of the PPK processing without GCPs are perfectly comparable with those of the PVs deriving from RTK analysis and show small acceptable small deviations (Bayanlou & Khoshboresh-Masouleh, 2020). The height differences between PVs measurements and those deriving from the DEM in the same planar coordinates vary between a minimum of 1 cm and a maximum of 7.8 cm (1 cm<IΔI<7.8 cm).

This goodness of the results was also achieved because we worked in very "favorable" conditions for the survey, consider that:

1) the NRTK measurement of the PVs took place with professional GNSS instruments;
2) the PPK reconstruction associated with the geotag of the photos taken by the drone used a latest generation GNSS receiver specifically for UAS;
3) in both previous cases the positions were corrected using the same GNSS Base (GRO1), i.e. a station with high-level professional characteristics (multi-constellation and multi-frequency professional GNSS receiver and professional choke ring type antenna).

All this has contributed to improving the accuracy and precision of the surveys.

The outcome can be defined as very satisfactory, with excellent photogrammetric resolutions and truly acceptable positioning errors, in fact the post-processing done using all the constellations is very stable and does not differ much from RTK positioning.

From the analysis of the results it can be concluded that:

- The innovative low-cost system for precision survey implemented on a “commercial and non-customizable” drone has proved to be effective and efficient.
- Precision mapping with a drone equipped with an on-board GNSS module does not differ much from the technique that involves measuring GCP on the ground, in reality, it is comparable in terms of errors, even on the more difficult field of altitudes.
- The use of drones and the technologies presented in this work allow us to reduce costs, time and use of human resources and above all to access areas that were difficult to explore until now.

Table 1 - DEM/PVs comparison.

CHECK POINTS (PVs)	LATITUDE	LONGITUDE	HEIGHT PV RTK (mt)	HEIGHT DEM PPK (mt)	DIFF PV/ DEM (mt)
PV1	41,068	15,102	394,74	394,662	0,078
PV2	41,067	15,102	394,903	394,868	0,035
PV3	41,067	15,102	395,117	395,132	-0,015
PV4	41,067	15,102	395,562	395,598	-0,036
PV5	41,067	15,102	395,867	395,801	0,066
PV6	41,067	15,102	396,382	396,308	0,074
PV7	41,067	15,102	397,501	397,515	-0,014
PV8	41,067	15,102	399,221	399,235	-0,014
PV9	41,067	15,102	398,396	398,358	0,038
PV10	41,067	15,102	397,85	397,805	0,045
PV11	41,067	15,102	397,098	397,152	-0,054
PV12	41,067	15,102	397,131	397,145	-0,014
PV13	41,067	15,102	397,168	397,193	-0,025
PV14	41,067	15,102	397,072	397,062	0,01
PV15	41,067	15,101	397,111	397,123	-0,012
PV16	41,068	15,101	397,084	397,056	0,028
PV17	41,067	15,101	397,115	397,152	-0,037
PV18	41,067	15,101	397,087	397,055	0,032
PV19	41,067	15,101	397,066	397,05	0,016
PV20	41,067	15,101	397,105	397,162	-0,057
PV21	41,067	15,101	397,07	397,081	-0,011
PV22	41,067	15,101	397,213	397,234	-0,021
PV23	41,067	15,102	397,09	397,052	0,038
PV24	41,067	15,102	397,162	397,185	-0,023
PV25	41,067	15,102	397,106	397,13	-0,024
PV26	41,067	15,102	397,087	397,098	-0,011
PV27	41,067	15,101	397,08	397,094	-0,014
PV28	41,067	15,101	397,74	397,662	0,078
PV29	41,067	15,101	397,903	397,868	0,035
PV30	41,067	15,101	397,117	397,132	-0,015

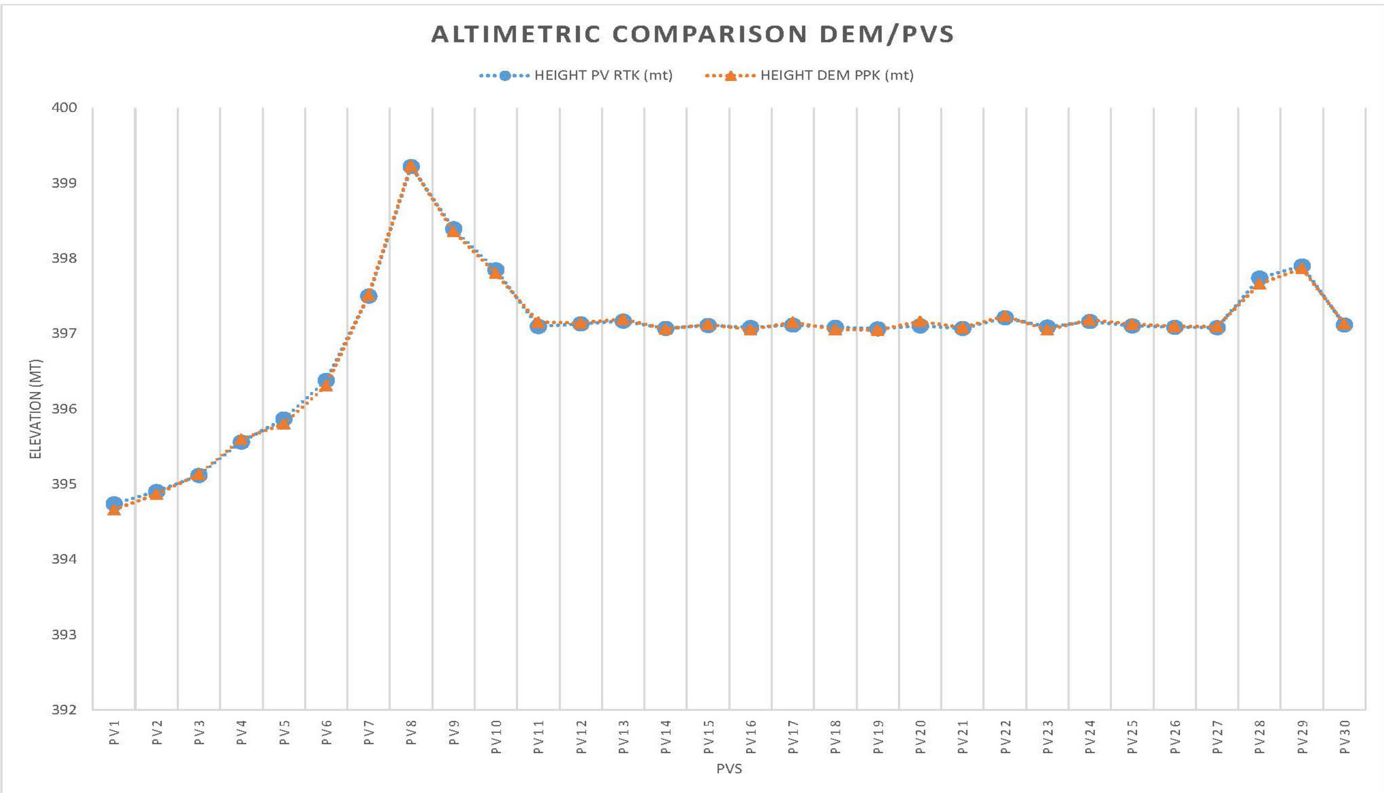

Fig. 4 - DEM/PVs comparison.

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