Low-cost aerial mapping and accuracy assessment using UAV internal parameters for Image georeferencing in undulating terrain

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Abstract*: *Unmanned Aerial Vehicle (UAV) photogrammetry is an area of immense potential emerging today highly efficient method for surveying small- or medium-sized areas. UAVs are providing a cheaper solution for obtaining very precise results in terrain mapping. The integration of the Real-Time Kinematic (RTK) / Post-processing Kinematic (PPK) Global Navigation Satellite System (GNSS) module on a UAV allows the reconstruction of a highly detailed and precise Digital Terrain Model without using Ground control points (GCPs) and provides the possibility to carry out surveys in high undulating areas. The combination of the internal flight parameters of the UAV with the geospatial parameters (multi-band GNSS) plays a major role to achieve high-end accuracy in UAV photogrammetric surveys. The objective of this study is to compare the RTK positioning accuracy with the PPK method. UAV data was processed by photogrammetric software Pix4DMapper, the RMSEz = 0.494451 m was calculated from the RTK data, while the data generated by the PPK method yielded a mean RMSEz = 0.313777 m. After careful and in-depth observation of all dimensions of the geospatial models, concludes that UAV data obtained by the PPK method is more accurate than RTK.

***Keywords*: Unmanned aerial vehicle (UAV), Structure-from-Motion (SfM), Real-Time Kinematic (RTK), Post-Processing Kinematic (PPK).**

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I. INTRODUCTION

There are some much-needed complex issues in the traditional methods of land mapping [1]. Several researchers have presented solutions to such objectives with the help of the DJI Phantom 4 for coastal mapping using RTK and PPK mapping techniques. Precision agriculture is also using drone technology with GPS and the multispectral sensor for crop health and yield estimation [2]. UAV technology is increasingly used in various areas of medical emergency and medical assistance operations in remote areas [3]. In today's era, the entry of UAVs is happening in all the fields related to human life [4]. Nowadays the utility of fast and good results in the field of mapping has increased a lot. Unmanned Aerial Vehicle (UAV) platforms have become a low-cost alternative to conventional methods for obtaining various dimensions of land area 3D mapping results. Whereas a modern high precise Differential Global Positioning System (DGPS) measurement system has been adopted with UAV for mapping of land areas that are not accessible by humans. These instruments are equipped with onboard geospatial parameters for accurate mapping like IMU (Inertial Measurement Unit) and accurate GNSS with UAV. UAVs are suitable for small-scale research applications, with a great potential for detailed restoration of a survey area. These aircraft should be considered as complete systems, as they feature many technologies and show great investigative skills [5]. Efforts being made for mapping very high and accurate direct georeferencing is proving to be of importance in many domains where UAVs have proved to be a boon due to their functionality such as monitoring of any infrastructure and expediting disaster response. Traditionally, images or video streams captured by UAVs were broadly referred to either through visual analysis in a given local coordinate context, which was later used by Geostationary Inter GNSS receivers from the ground [6]. Acquisition of GCPs from the ground in high undulating areas is limited by many difficulties or hazardous conditions, but direct georeferencing can also be used to increase the accuracy of the mapping. UAV images can be established in a World Geodetic System by accurately measuring the geospatial position and orientation of the sensor [7]. The accuracy of the survey carried out by UAVs depends on several parameters, including the method of capturing the data used, the precision of the instrument, and the sensor being used to capture the data from the ground with maximum accuracy. The precise measurement of the GCP collected from the ground also influences the resulting manifold at the time of data processing. Typically, surveyors are expected to make extensive efforts in terms of time and accuracy to collect GCPs, while it is also worth noting that such areas are often inaccessible.

II. UAV Surveying Methods

A. Real-time kinematic (RTK)

RTK technology to improve the location accuracy of GNSS receivers to the centimeter level by applying correction messages from the reference base station. A reference station is a fixed location that calculates the actual offset from its actual position via satellite signals. An operational base station on the ground delivers raw GPS data to the drone while it is in flight. The drone's inbuilt GPS uses that information together with its observations to estimate its exact location with the base.

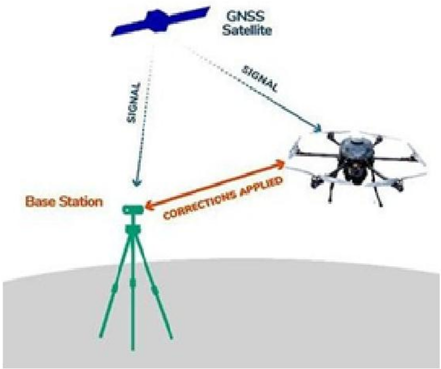

Fig. 1. RTK method for applying the correction.

The Radio Technical Commission for Maritime Services (RTCM) is a messaging system that receives a correction message from a reference station. RTK-enabled UAVs can accurately track their position in real-time during autopilot missions, which regular UAVs lack [8]. RTK UAV needs a reference station correction message via radio or network system while collecting the data. Unfortunately, a connection may be lost during flight, resulting in loss of message integrity, possibly due to a loss in antenna orientation or the break-in radio network. Due to this, the GPS has difficulty in getting the fix of its position, then the data received becomes unreliable. In today's modern era, new methods and techniques have been developed in this field and they have been applied and tested. One of these includes an additional airborne high precision GNSS device (the default GPS receiver of UAVs is used for navigation) to perform precise geotagging of images in the real-time field environment of UAV flight [8].

B. Post-Processed Kinematic (PPK)

The PPK method is an alternative to the RTK method. This method is used because the speed of the UAV is very high during the mission, so it is challenging to measure the correct position, hence the PPK method is used. This method does not require any type of correction link (radio or GSM) link between the base and the rover, which simplifies setting up the system on-site. In which the position of the trigger event is obtained by processing the raw data files of the base station and rover (airborne GPS).

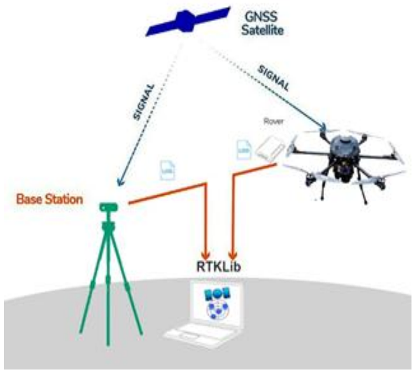

Fig. 2. PPK method for data processing.

By merging the image position value with the yaw, pitch, and roll value received from the flight controller, a CSV file is obtained which is used for data processing in Pix4D mapper software. Various geospatial data models were obtained by processing the data in Pix4D mapper, from which we used GPS-assisted ground points DTM with DTM made from UAV data for accuracy assessment and measured the amount of error [9][10].

III. Study Area

The area for this study is taken as the small part of the bank of Solani River shown in Figure 3. which flows from the north side of Roorkee city. It is generally like a rainy river, in which there is very little water throughout the year. The geographic extent of the Solani River expands from 29° 52' 15" to the North and 77° 54' 50" East covering an area of 8.11 square kilometers.

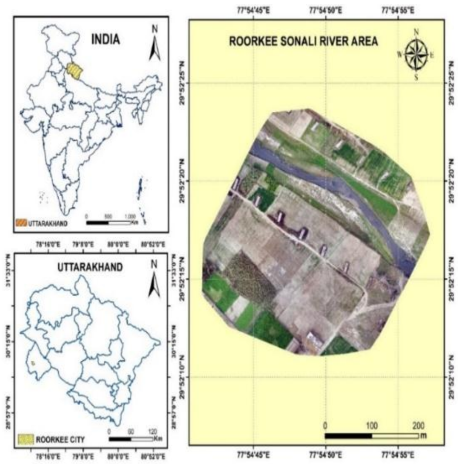

Fig. 3. Study area map.

Since the purpose of this study was to test the data taken by different methods of a UAV survey on high undulating terrain. The available undulating area near the lab had to be selected to make the study materialize. This covers an area of 0.122 sq km on both the banks of river Solani. Which is an area having a larger variation of DTM in Roorkee city.

IV. Instrument Used and Flight Plan

In terms of obtaining ground survey data, we have implemented a system in which survey data is acquired using an indigenously developed Hexacopter (Inferno Hex) with the following specification given in Table1.

TABLE I. INSTRUMENT USED FOR DATA ACQUIRING AND INTRINSIC CAMERA PROPERTIES.

Parameter	Specification
Flight Controller	Cube black
Rotor	6
Camera	Sony Alpha 6000
Pixels	24.3MP
Sensor	APS-C type (23. x15.6 mm)
Telemetry	RFD900+
GPS	Here+(Internal) Emlid Reach M2(External)
GPS for Base and GCP	Spectra Precision -60
Ground control station	Mission Planner

UAV carrying a camera as a payload for aerial surveying. The total weight of the UAV was 3.7 kg, which is compatible with these motors and propellers to achieve maximum endurance.

Fig. 4. Reach M2 multi-band GNSS receiver with SMA antenna.

UAV has an autonomy of flight of about 18 minutes. The UAV is equipped with a Sony Alpha 6000 camera below the center of the UAV based on the APS-C type (23.5 x 15.6 mm), Exmor™ APS HD CMOS sensor. The aerial Imaging camera is triggered using a Drotag cable. The platform is airborne with a highly compact multi-band (L1 and L2) ReachM2 GNSS receiver with an SMA antenna as shown in figure 4(Cramer et.al.2021).

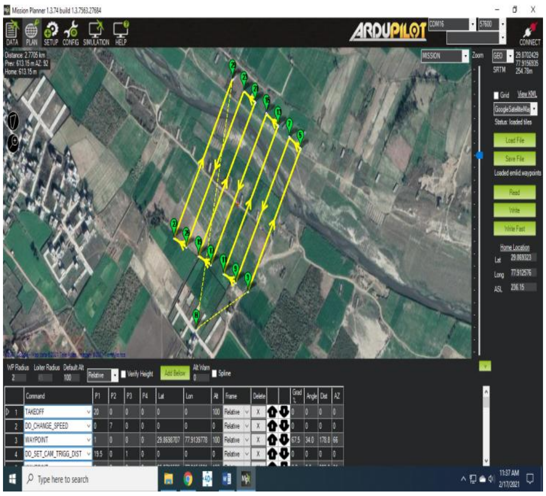

Fig. 5. Flight plan in mission planner for the area of interest.

Flight planning for the aerial mapping was done using an ardupilot open-source software mission planner which provides various versatility for autopilot missions. The mission planner has a facility to provide a survey grid for the area of interest and load generated waypoints in autopilot. Aerial mapping using a mission planner was done with the following parameters.

TABLE II. FLIGHT PARAMETERS OF UAV.

Parameter	Value
Area of interest	0.122 km^2
Flying height	100 meters
Front overlap	70 %
Side overlap	75 %
Focal length	16 mm
Exposure Time	1/1600 second
F-stop	f/6.3
Max aperture	3.6171875
Speed	7 m/s

Fig. 6. Base setup for GNSS receiver, UAV, and GCP marking.

SP-60 used for reference station for RTK mode provides real-time correction for ReachM2 module. A radio communication system was used to correct position when the UAV is capturing photos of the area of interest. In PPK mode to correct the position, we set up a Base in a static mode that stores data for position correction in its internal memory, which will then be retrieved and processed with the ReachM2 data to get an accurate position for Image georeferencing.

To assess the positional accuracy of the UAV, a ground grid survey, as well as a GPS survey, was conducted to collect GCPs from the ground. As shown in figure 6, the base has been established for the PPK method which can store the data in static mode by filling the input parameters with the help of the controller of the GNSS receiver [11]. As we can see in the graph the altitude trend in the graph shows that the variation in PPK triggered events is less than that of RTK triggered events due to UAV mobility in autopilot.

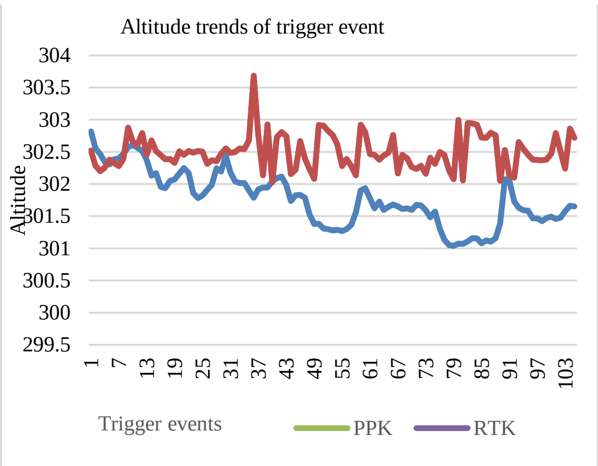

Fig. 7. Altitude trends of PPK (red) and RTK (blue).

Due to its environmental impact, the UAV changes its position and altitude very rapidly at flight speeds of 7 m/s, making it very difficult to maintain accurate measurements by GPS even after base correction is applied. The variation in height is more visible in the RTK data [12].

V. METHODOLOGY

The traditional methods of doing ground surveys by GPS already exist, which are used to mark points on the ground of any area and to collect survey points. But today the utility has increased significantly, offering very high-quality geospatial data model solutions for any small area survey. As mentioned above, the orientation parameters of the flight controller are used to combine the position of the image stored by the Reach M2 GPS module.

The flight controller triggers the camera's shutter each time a waypoint is reached, thereby saving positional parameters for each trigger event in the Reach M2 internal memory. In the RTK method, with the help of the correction message received from the reference station, they correct the positional accuracy during their flight so that they do not need to be processed later. The entire process explained so far was done before processing the data. The focus was on precise georeferencing of the aerial Images by combining the positional parameter obtained from the ReachM2 module with the autopilot orientation parameter (yaw, pitch, and roll).

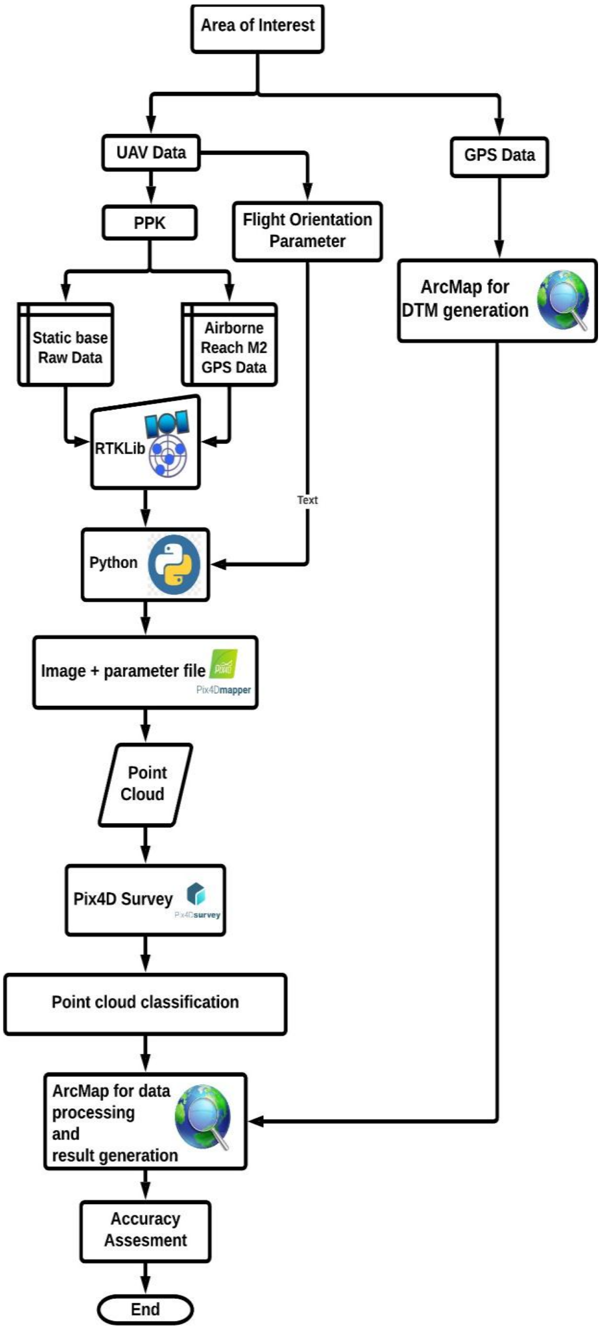

Fig. 8. Flow diagram of a methodology for accuracy assessment.

When the data were processed in photogrammetric software with all these factors, the resulting geospatial data models were generated, which are shown through different layers in Figure 13. Since the accuracy of the DTM depends to a large extent on the classification being performed during processing [13]. There is a possibility of some errors in the geospatial results obtained from the processing of Pix4D, which can be obtained by manually classifying the point cloud obtained from Pix4DMapper with the help of any other point cloud processing software.

Carry out a precise assessment of the accuracy of UAV data so again export dense point clouds from the Pix4DMapper to the Pix4D Survey by running a terrain filter and grid point process to post-process dense point clouds. Pix4DSurvey can classify point clouds into terrain and non-terrain classes and generate representations of the land surface using only terrain points by doing manual efforts, leading to the generation of more accurate and precise DTM with the help of ArcMap. The altitude of the UAV at the same position was compared with that of the ground surveyed GPS point and GCP point so that the value obtained from the data of the UAV relative to the ground point is seen in the same position, ArcMap provides such facility to do a comparative study of the points of two DTMs [14].

VI. Results

The SP-60 GNSS receiver was used to do the ground survey of the area of interest (WGS 84 UTM 43 N zone) to compare the accuracy of the data acquired in RTK and PPK methods. The highest elevation of the surveyed area is 255. 8176 meters and the lowest elevation is 254.34 meters. The difference between the highest altitude and the lowest was found to be 1.4776 m, indicating that the terrain of the survey area is full of fluctuations [15].

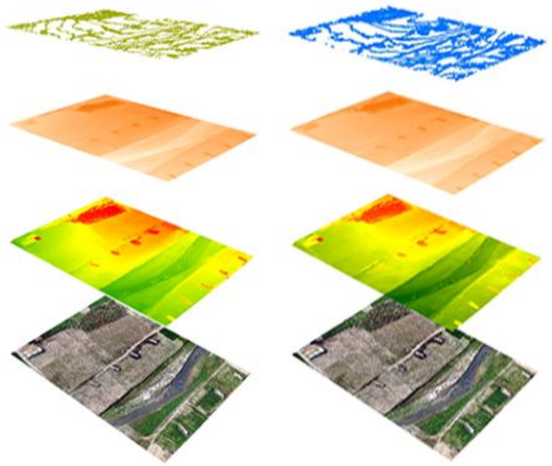

Fig. 9. Geospatial data models are generated by Pix4D by processing (left) RTK data (right) PPK data.

In the diagram, there is a visual representation of the products with a geomatical orthomosaic map. Figure 9 shows the various geospatial data models as well as processed by the RTK method data processed in pix4d on the left. The right side shows the geospatial models generated by the PPK method. The data obtained by the RTK method adopted for mapping by UAV yielded a 2.41 cm GSD value while 2.42 cm average GSD was obtained from the PPK method although the purpose of the test by both the methods was to achieve a minimum value of 2.5 cm GSD. When it comes to checking the accuracy, the height of the GCP is compared with the height generated from the DTM with the results obtained by both methods, but the projection system of the coordinates must remain the same throughout the comparison [16]. There is no straight method to compare both the data directly, so it was solved with the help of GIS (geographical information system) software like ArcMap. The GCP values were imported and compared by importing the RTK and PPK data in turn, the details of which are given in the table.

TABLE III. COMPARISON OF DTM GENERATED BY PIX4DMAPPER.

Validation Points				Results generated in Pix4DMapper			
GCP	Northing (m)	Easting (m)	Elevation (m)	RTK (m)	PPK (m)	Error_RTK (m)	Error_PPK (m)
G1	3308241.707	781437.2082	254.4179	254.7292	253.9122	-0.3113	0.5057
G2	3308208.875	781509.9025	254.5949	253.9414	254.3607	0.6535	0.2342
G3	3308179.174	781374.1682	254.4017	255.0224	254.1524	-0.6207	0.2493
G4	3308165.31	781596.739	254.5765	253.976	254.2305	0.6005	0.346
G5	3308059.302	781508.3059	254.8312	254.1171	254.3988	0.7141	0.4324
G6	3308058.344	781326.0976	255.2537	255.4193	255.0043	-0.1656	0.2494
G7	3308027.204	781411.0414	254.8648	254.5838	254.9698	0.281	-0.105
G8	3307942.246	781464.6416	254.5806	254.3166	254.3935	0.264	0.1871

TABLE IV. RESULT OF RTK AND PPK MODE WITHOUT GCP.

Parameter	RTK_Pix4D	PPK_Pix4D
Average	0.1769375 m	0.2623875 m
Standard Deviation (SD)	0.493587859 m	0.183953623 m
$RMSE_z$	0.494451 m	0.313777 m

The corresponding DTM generated from the RTK and PPK data collection techniques when compared with the GCP is clear that the results obtained in the PPK are much closer to the value of the GCP than in the RTK. It can be understood through Figure 10 that the fluctuation in the graph of RTK is high, while the graph of PPK is largely following the graph of GCP.

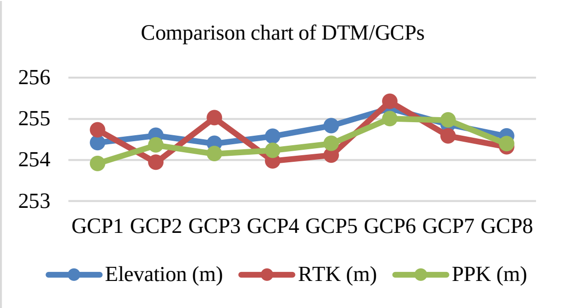

Fig. 10. Comparison chart of DTM/GCPs.

Till now a comparative study of the results extracted from the data of RTK and PPK processed with the help of Pix4DMapper was done. It is observed that the accuracy of the DTM made from Pix4DMapper is not so much, because the point cloud generated in it does not classify the human structures properly leading to errors in generated geospatial data models.

For the proper solution to this problem, you can proceed to a conclusion with the help of Pix4DSurvey to classify point clouds by setting ground above height to 5 cm by removing crops of sugarcane and high vegetation objects with man-made structures. The point cloud was manually classified, then a 2.5-meter point grid was generated and the DXF file was exported to ArcMap to enable DTM realization [17].

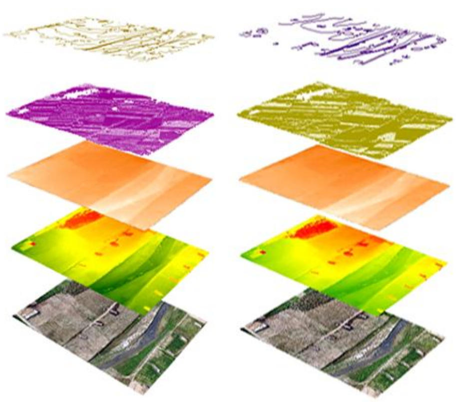

Fig. 11. Geospatial data model generated by Pix4DSurvey (left) RTK mode (right) PPK mode.

In the geospatial data model shown above, 1 layer has been added and 4 is refracted in the same way, the fifth layer is shown the point grid made by Pix4DSurvey. Comparing the results provided by Pix4DSurvey concerning GCP in ArcMap gives the following result shown below. Note that GCP was not used for data processing in the results shown when the findings were studied. In the geospatial data model shown above, 1 layer has been added and 4 is refracted in the same way, the fifth layer is shown the point grid made by Pix4DSurvey. Comparing the results provided by Pix4DSurvey concerning GCP in ArcMap gives the following result shown below. Note that GCP was not used for data processing in the results shown when the findings were studied.

TABLE V. COMPARISON OF DTM GENERATED BY PIX4DSURVEY.

Validation Points				Results generated in Pix4DSurvey			
GCP	Northing (m)	Easting (m)	Elevation (m)	RTK (m)	PPK (m)	Error RTK (m)	Error PPK (m)
G1	3308241.707	781437.2082	254.4179	254.6782	253.9172	-0.2603	0.5007
G2	3308208.875	781509.9025	254.5949	254.0544	254.3814	0.5405	0.2135
G3	3308179.174	781374.1682	254.4017	254.9804	254.1564	-0.5787	0.2453
G4	3308165.31	781596.739	254.5765	253.955	254.615	0.6215	-0.0385
G5	3308059.302	781508.3059	254.8312	254.1131	254.4981	0.7181	0.3331
G6	3308058.344	781326.0976	255.2537	255.5753	254.9893	-0.3216	0.2644
G7	3308027.204	781411.0414	254.8648	254.4938	254.5618	0.371	0.303
G8	3307942.246	781464.6416	254.5806	254.7815	254.4435	-0.2009	0.1371

TABLE VI. RESULT OF DATA IN COMPARED FOR RTK AND PPK MODE.

Parameter	RTK_Pix4DSurvey	PPK_Pix4DSurvey
Average	0.1112 m	0.244825 m
Standard Deviation (SD)	0.504157677 m	0.155788875 m
$RMSE_z$	0.484529 m	0.284913 m

If we look at the results obtained after data processed in Pix4DSurvey RTK does have RMSEz 0.484529 m, while PPK produces 0.284913 m which is less as compared to RTK. After filtering and purifying the data in Pix4D, the test results show that the accuracy of the data georeferenced through the PPK method is higher than that of the RTK method [18]. A comparative study of the above accuracy vertical error results is quite clear that the data georeferenced by the PPK method is more accurate as compared to RTK [19].

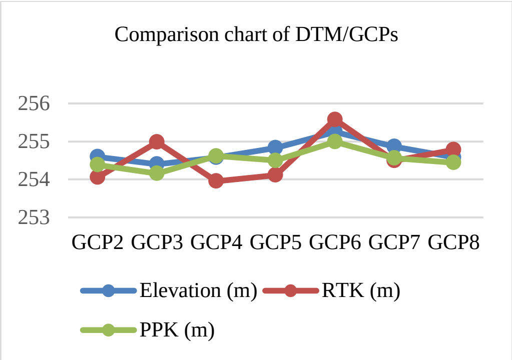

Fig. 12. Comparison chart of DTM/GCPs.

It is completely clear that UAV data is processed by georeferencing with the PPK method and combined with orientation parameters, the results are obtained more accurately than RTK.

VII. Discussion

The study aimed to evaluate the accuracy of the images georeferencing by RTK and PPK methods. For this, the data was processed by incorporating the orientation parameter along with the GPS position of the UAV. This study was based on a different analysis of the results than the conventional approach in the photogrammetric field where the point cloud and the extracts of all the resulting products were measured both by marking the GCP and using only the positional (latitude, longitude, altitude) and orientation (Yaw, Pitch, Roll) parameters without using the GCP. This work mainly focused on the results obtained from two different photogrammetric software by directly providing real-time correction messages to ReachM2 GPS in RTK mode and data obtained after post-processing in PPK mode using the same reference station. Based on the results obtained from the photogrammetric processing of the survey with the height of the DTM and the height of 8 GCP wanted to make a comparison between the resulting height for measurements taken in RTK/PPK mode. The configuration of the entire setup used can be described as follows.

- The SP60 is a state-of-art GNSS receiver that conveniently provides a high degree of flexibility to meet any demand for accurately georeferenced data relative to the ground from UAV images with GIS applications up to sophisticated RTK enabled solutions. The SP60 receiver provides the most reliable measurements and the highest possible accuracy under any conditions, anywhere in the world.

- Geospatial data models reconstructed by earlier photogrammetric surveys have come to the fore convincingly that the maximum distribution of GCP over the area of interest is necessary for good georeferencing. When your area is quite fluctuating, marking the GCP in the right places gives very accurate results, otherwise, there are many shoot variations in height.

- The camera is fixed at the bottom central part of the UAV frame, using the flight controller's internal parameters (positional and orientation) to define the derivatives of the results, which was the stated objective of this study.

- The data captured by the RTK method and PPK is processed in both software Pix4D Mapper and Pix4DSurvey to assess the accuracy with the help of ArcMap.

VIII. Conclusion

The present study aims to obtain an accurate geo-reference of photogrammetric products processed with and without GCP with PPK techniques for RTK correction data obtained from the reference station and with raw GNSS data. Also intended to test the capability of the airborne Emlid Reach M2 multi-band GNSS receiver with UAVs in aerial mapping applications. In this paper, we wanted to show that while the GNSS basis for RTK and PPK varies, the solutions also differ, but remain comparable with limited error ranges. The error was quantified by comparing the resulting DTM of the expansions by processing the ground-acquired GCP measurements by the SP60 with the data obtained from RTK and PPK Techniques in two different software. So our goal was to investigate how processing affects the final solution. It was shown that working differently, that is, concerning a reference, yielded different results in terms of absolute accuracy, but they were still completely comparable. Considering the high undulating terrain for precise positioning with the UAV, a variation of results between 10-20 cm can be considered substantial, especially in places where access is difficult. The results obtained by the RTK and PPK methods can be defined as satisfactory with good photogrammetric resolutions and acceptable position errors. Based on these results, it can therefore be said that accurate mapping with a drone equipped with an on-board GNSS module is not much different from the technique that involves ground measurement of the GCP, to achieve accuracy if GCP was used in the processing. It can be scaled up a lot and this technology can be put on par with professional mapping drones and found to be comparable even in the area of undulating terrain in terms of precise measurement and mapping. In today's era, continuous technological advances in the fields of geodesy and UAV aerial mapping drive us to always search for new solutions that allow us to reduce the cost, time, and use of human resources, and above all, those Can be useful for examining areas that are difficult to locate or areas prone to natural disasters. The ability to adequately forgo the measurement of the GCPs is an obvious benefit in the context of quick mapping when the timing is a determining issue.

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