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Accuracy of a Low-cost Autonomous Hexacopter Platforms Navigation Module for a Photogrammetric and Environmental Measurements

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Abstract. A photogrammetry and environmental measurements from an unmanned aerial vehicle (UAV) are a low-cost alternative for a traditional aerial photogrammetry. A commercial off-the-shelf products (COTS) offers a variety of cheap components that a suitable to be used on board a UAV. In this paper a low-cost navigation module based on Ublox NEO-M8N GPS and Pixhawk flight controller have been described, as a main extrinsic parameters source for aerial photogrammetry, mounted on autonomous hexacopter platform. An accuracy of navigation data logged during the drone flight by a flight controllers navigation module has been compared with geodetic reference measurement. A man controlled flight modes has been tested during a drones loitering above designated point. Due to the situation that, a variety of active electronic, radio transmitters, navigation, inertial and magnetic sensors, are to be placed on a relatively small hexarotor platform with high current power system, overall interference between electronics have to be considered. Paper presents results of navigation module fine tuning process and some technical issues solved during research, that caused an accuracy improvement and interference diminishing. Detailed results are presented and concluded as for the accuracy of navigation based on cheap GPS module is satisfied for execution an autonomous photogrammetry and environmental tasks.

Keywords: drone, uav, photogrammetry, navigation, open-source, pixhawk.

Conference topic: Technologies of geodesy and cadastre.

Introduction

Todays, a photogrammetry and environmental measurements from a unmanned aerial vehicle (UAV) are a low-cost alternative for a traditional aerial photogrammetry. Low-cost satellite navigation technologies available on market are suitable to be used on board aerial vehicles. A commercial UAVs can be are defined as a commercially available and manufactured by a one company complete product designed and optimized for aerial photography and videography.

The commercial UAVs are using one frequency GPS modules to calculate vehicle geographical position in order to support loiter flying mode. In loiter mode vehicle automatically attempts to maintain the current location, heading and altitude. In this mode the pilot may fly the vehicle as if it were in manual flight mode, but when the control sticks are released, the vehicle will slow to a stop and hold position. This means that, the GPS coordinates are used to maintain vehicle 3D position in open environment. For this fly mode a GPS satellite signal reception is crucial, and any satellite signal loss will unable to vehicle to take-off safely and enter in loiter mode. On board non-commercial UAV, a GPS readings can feed different navigation systems, especially autonomous navigation patch planning and execution.

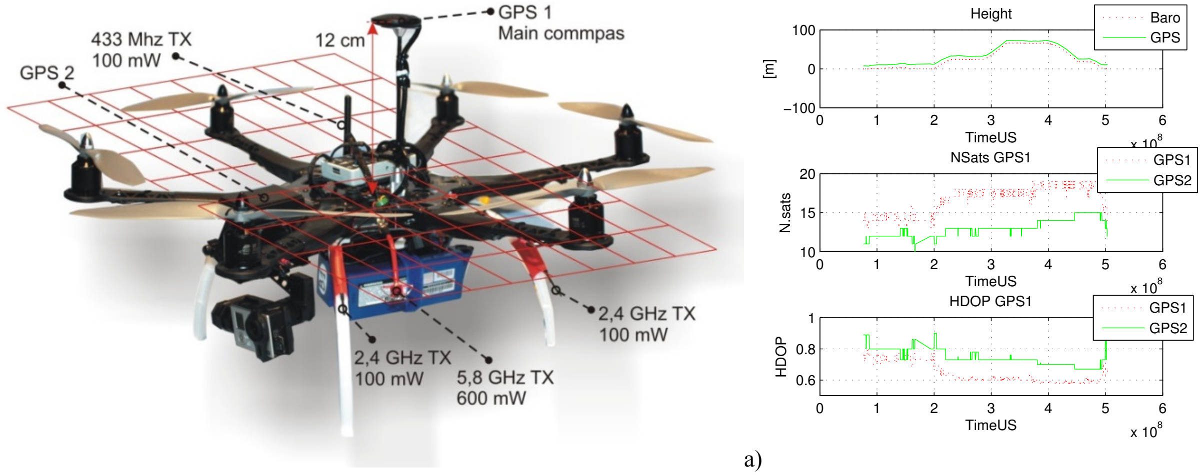
The UAV

The tested UAV platform (Burdziakowski 2017) is equipped with two GPS modules. The main module (GPS1) is placed on carbon mast, 12 cm above top frame plate (Fig. 1a). The GPS1 was moved upwards to diminish electromagnetic interference (EMI) form ESCs (electronic speed controller), video and telemetry transmitters (placed between a top and bottom main frame plate) and main power high current cables. The second (GPS2) is placed above a CCD sensor on the same level as the top frame plate. The GPS2 has been modified. A standard PCB 25 mm/2mm ceramic GPS antenna (ANT1575-2520A) has been removed and new PCB ceramic antenna 25mm/4mm (ANT1590-2540A) has been soldered. This modification allows to receive GLONASS satellite system signal (antenna is tuned for GPS and GLONASS frequencies) (Table 1). Both GPS modules (UBlox M8N) have been activated to receive GPS and GLONASS satellite navigation systems. FC (flight controller) has been configured to receive satellite position from both receivers, but for navigation system only source with lower HDOP value is selected by FC algorithm. During stationary tests the modified receiver (GPS2) received signal averagely form 3 more satellites than standard one. Due to that reason the GPS2 was mounted with closer distance to electromagnetic source on board UAV.

Table 1. GPS antennas characteristics (TME-Electronic)

Items	ANT1575-2520A (GPS1)	ANT1590-2540A (GPS2)
Nominal frequency MHz	1575.42±1.023	1575~1608 (GPS: 1575, GLONASS : 1598~1608)
Center frequency MHz	1575±3.0	1597.5±3.0
VSWR at Fo max	1.5	14
Return Loss at 1585 MHz max dB	–2.61	–7
Return Loss at 1610 MHz max dB	–2.61	–7
Impedance(Ω)	50	50
Polarization Model	RHCP	RHCP
Frequency Temperature Coefficient	20ppm/deg.℃ max	20ppm/deg. ℃ max

A test flight shows a differences between number of satellites (NSats) received and a HDOP between both GPS receivers (Fig. 1b). The GPS2 was affected by EMI (electromagnetic interference) and received less number of satellites. A high buildings in test area covers satellite signal reception on lower altitude. At the higher altitude both receivers NSat (number of satellites) increases and HDOP (horizontal dilution of precision) is decreasing.



a) b)

Fig. 1. GPS modules and EMI sources localization on board UAV (a), number of satellites and HDOP in height domain (b)

Loiter fly mode

GPS modules are calculate vehicle geographical position in order to support a loiter flying mode. In the loiter mode vehicle maintains the current location, heading and altitude – desired position. All sensors inputs are calculated using EKF (The Extended Kalman Filter). The GPS position is a part of all inputs. The vehicle position (calculated using EKF) can be different than pure GPS readings. The EKF algorithm uses 3 gyroscopes (GYRO), 3 accelerometer (ACCEL), 2 compass (COMP), 2 GPSs, and 1 barometric (BARO) pressure measurements to estimate the position, velocity and angular orientation of the vehicle. When the GPS measurement arrives, the filter calculates the difference (innovation) between the predicted position from inertial part and the position from the GPS. The innovation, state covariance matrix, and the GPS measurement error are combined to calculate a correction to each of the filter states (state correction). The used ArduCopter firmware (v 3.4.3) uses a 24 state EKF to estimate the following states (Ardupilot 2016): Attitude (Quaternions), Velocity, Position, Gyro bias offsets, Gyro scale factors, Z accel bias, Earth magnetic field, Body magnetic field, Wind Velocity.

The vehicle horizontal position is delivered by the GPS and INS XY modules, and this is considered as a main source of horizontal position (Fig. 2). The vehicle vertical position (altitude) is delivered by a barometer sensor and INS Z and GYRO Z calculation. The GPS height is not considered as an altitude reliable source, due to a reading fluctuations. Fig. 3 presents altitude reading from a different source during one flight.

A significant differences is observed between GPS1 and GPS2 altitude. AHR2 Alt is a barometer altitude plus home altitude (GPS altitude obtain in home/start position), POS Alt is EKF Altitude output. During the flight POS Alt is corrected. It is clearly visible on Fig. 3 in the first phase of flight, where EKF is correcting the POS Alt, based on IMU/GYRO Z, BARO and GPS Alt.

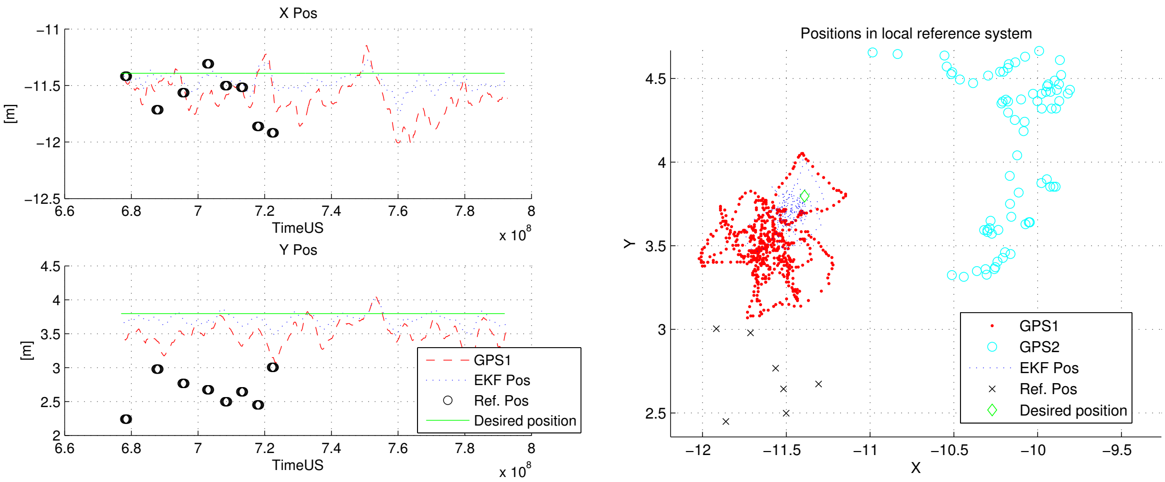


Fig. 2. XY positions form different UAVs navigations system

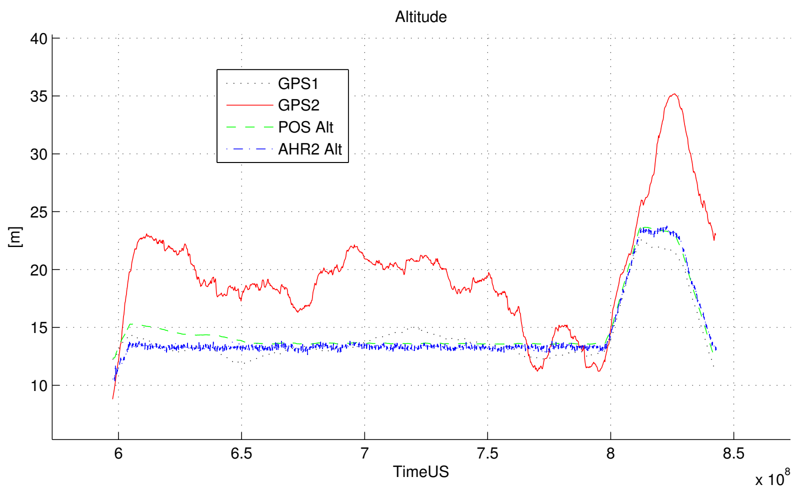
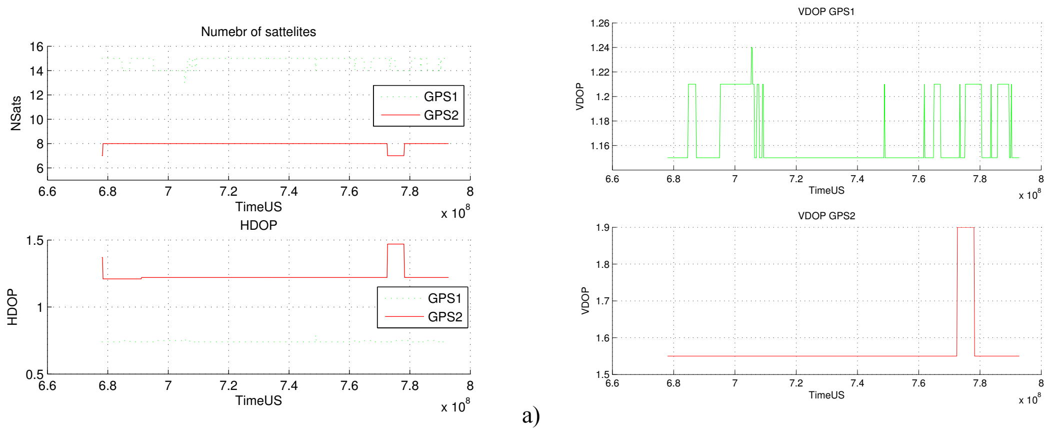


Fig. 3. Altitude sensor readings – differences and VDOP

On board UAV, in loiter fly mode X and Y axis location is GPS dependent, Z axis is BARO dependent. For direct photo georeferencing (Grejner-Brzezinska 2000) GPS location can be considered for X and Y axis, and Z axis can be considered only form POS Alt, which is EKF output for altitude. This is also important that after a fast altitude changes EKF output POS Alt requires some time to calculate altitude value.

Data acquisition

The field works were carried out on the Gdansk Technical University campus. A test flight was planned and executed in good weather conditions and with a wind speed of 1 to 2 m/s NE direction, temperature 3 deg. C. The GPS receiver of the UAV was operated on the ground before and after the flight. Each test flight was carried out only after GPS1 and GPS2 fixed maximal number of satellites on tested position. The UAV was cooled down to an air temperature, before test flights. It remained minimum 30 minutes in tested environment. The cooling down process is required to minimalize GYRO and ACCEL bias. The test field is considered as a not good GPS environment. GPS2 fixed considerably lower number of satellites (Fig. 4) during the test flight. It has to be mentioned, that in good environment of at the higher altitude used GPS modules can fix maximal 20 satellites.



a) b)

Fig. 4. Satellites reception during test flight a) NSAT and HDOP, b) VDOP

Measurement system setup

The drone flight data was logged on board flight controller and on the ground station. Two synchronized cameras was triggered simultaneously with RC channel number seven (RC CH 7) (Fig. 5). The high PWM signal state of RC CH7 allowed to trigger cameras and synchronize with FC system time (TimeUS). This synchronization method allowed to compare channel state with system time (TimeUS) and referenced photogrammetric position. The reference drone position (Fig. 2) was obtained based on images from two synchronized cameras (Janowski *et al.* 2016; Janowski, Szulwic 2014). Stereopairs were developed in the Image Master. This allowed the position measurement of the antenna. The reference position referred to Poland 2000 coordinate system (zone 6) – EPSG:2177. GPS logged position was recalculated to Poland 2000 coordinate system.

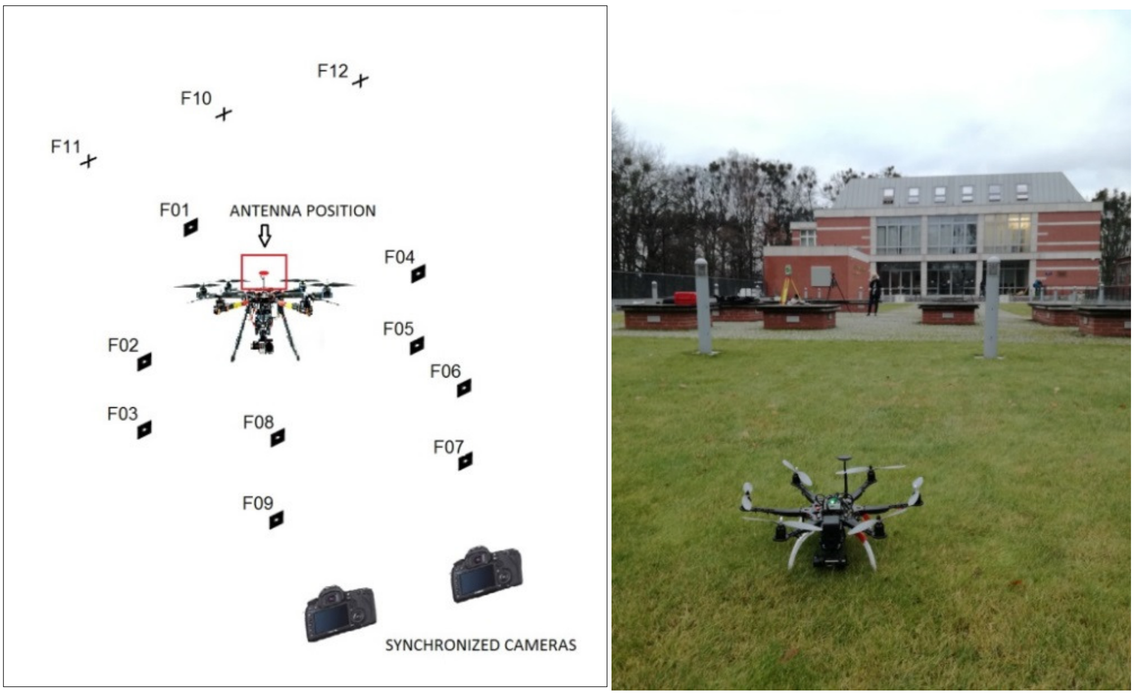


Fig. 5. Measurement system setup

Evaluation

Standard deviation and accuracy measures for the presented UAV navigation system are calculated in accordance with equations presented in (NovAtel 2003) and results for each system are presented in Table 2. Visualization 3D position accuracy measures for GPS1 are presented in Fig. 6. Height (z axis) is a GPS altitude for all calculations.

Table 2. The drone position navigation systems accuracy measures

Accuracy Measures	GPS1	GPS2	EKF pos
δX	0.1618	1.0769	0.0937
δY	0.1777	2.1434	0.0736
δZ	0.7546	3.1162	0.0284
SEP	0.5580	3.2316	0.0998
MRSE	0.7919	3.9325	0.1225
90% Spherical Accuracy Standard	0.9114	5.2783	0.1631
99% Spherical Accuracy Standard	1.2275	7.1096	0.2197

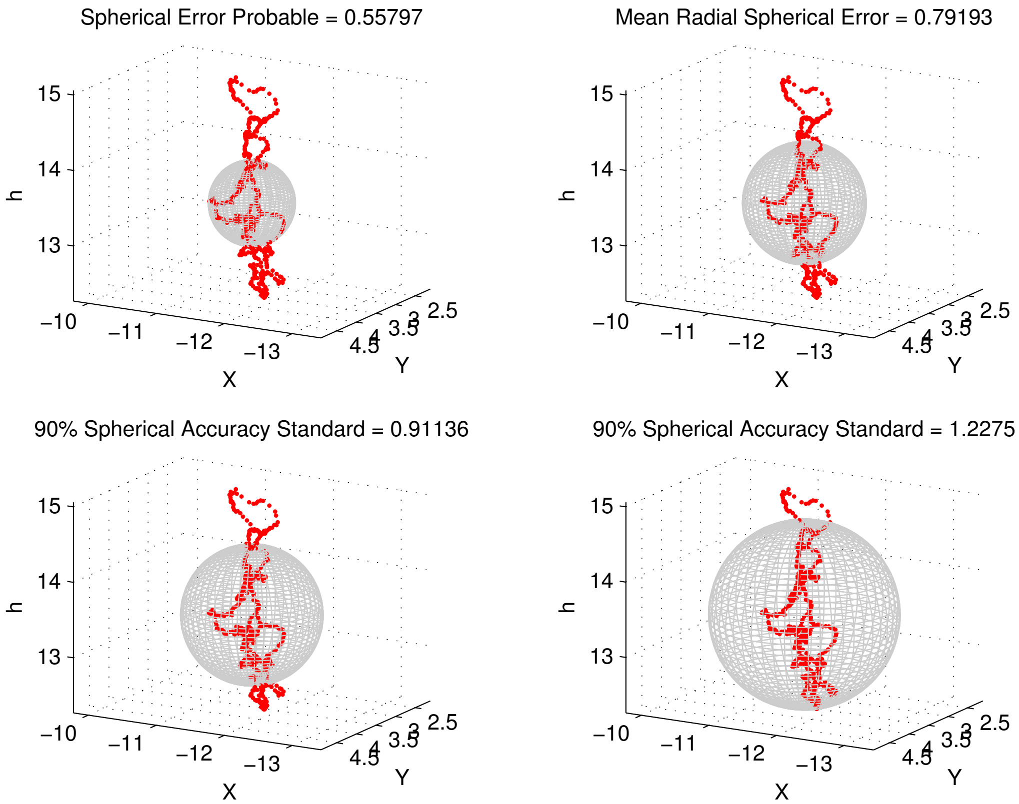


Fig. 6. 3D position accuracy measures GPS1 – visualization

Conclusions

The paper presents results of navigation accuracy of cheap navigation modules installed on board UAV hexacopter platform. As the result shows, GPS1 module mounted on small carbon mast presented a significantly better accuracy than GPS2, mounted in close distant form EMI sources. The offset between navigation systems was observed. Currently, flight controller system cannot consider offsets between navigation systems. There is no possibility to calculate offsets during the flight. It can be calculated during post processing.

Due to the fact, that the wind blew the drone, it could not reach desired position. N-NE wind blew drone to S-SW direction. Navigation system GPS1 and INS recorded that, however the real drone position has been moved a bit more than GPS and INS recorded. It can be solved in the future using navigation offsets and wind corrections.

An intensive growth of commercial exploitation of low-cost UAVs, the accuracy of positioning using GPS techniques should be taken into account. Awareness of this technology work is very important when raids are carried out in urban areas with a high infrastructures. In the case of air raids on open areas, e.g. around the coastal strip for analysis cliffs (Szulwic *et al.* 2015) or monitoring of sea vessels movement (Bobkowska 2016), high navigation accuracy is not necessary. In such a case, supervision raid, even without a navigation module, through observation drone, is possible.

A future work is planned for develop the presented analysis. A reference position can be obtained using method in (Wierzbicki, Krasuski 2016) during an open area flight. Area chosen for a future work should be widely open for a GPS signal in order to carry out the off with maximum number of satellites (20 satellites).

Authors declare that there is no competing financial, professional or personal interests from other parties, as far as presented research is concerned.

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