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Assessment of the accuracy of positioning unmanned aerial vehicles

Abstract

The paper discusses results of tests designed to determine the position stabilization accuracy of an Unmanned Aircraft System. The tests were carried out on a DJI S900 device featuring a A2 flight controller during basic flight operations. All the maneuvers were performed in the remote control mode with RC system, while the UAV's position was stabilized by its onboard systems. During all the tests, state-of-the-art surveying equipment was used to determine the position of the UAV. An analysis of the obtained measurement data has enabled the verification of the UAV positioning accuracy parameters specified by the manufacturer of the UAV. It has also allowed the assessment of onboard system indications in terms of their reliability in missions involving documentation photography, video shooting or professional photogrammetric documentation. The proposed set of tests, including the testing methodology, can successfully be applied in the future to inspect the operation of this type of equipment.

Keywords: UAV, hexa-rotor aircraft, position stabilization, position accuracy.

1. Introduction

In recent years, the development of Unmanned Aerial Vehicles (UAVs), or ‘drones’, has grown dramatically. Just 10 years ago this technology was barely known and used mainly in the military. Today millions of UAVs are deployed for a wide variety of purposes worldwide [1].

The history of Unmanned Aerial Vehicles dates back almost as far as that of manned aircraft. As has been the case with many advanced technologies, UAVs were initially developed to meet the growing needs of the military. The first attempts at constructing and deploying this technology took place during World War I. However, it was in 1930 in the United States that the first mass-produced drone was designed. The dynamic evolution of military Unmanned Aerial Vehicles began in the 1990s. The civilian market did not realize their enormous potential until the early 21st c. Currently, the technology has become very popular, and micro-UAVs are one of the fastest growing aviation sectors [1, 2, 3].

Unmanned Aerial Vehicles allow different sorts of data to be collected from a flight level. What is more, they are relatively cheap and easy to operate. For these reasons, measurement platforms of this kind are growing more and more popular. It must be added that Unmanned Aerial Vehicles feature a number of electronic systems that facilitate their operation [4, 5], including onboard computers which control the whole vehicle and position stabilization GPS/INS systems (Global Positioning System/Inertial Navigation System) [6, 7]. Therefore, a question arises as to how accurate the positioning of UAVs in the air is and whether the obtained values are consistent with the manufacturer's specification. This is an especially important issue in surveying and photogrammetry, disciplines which require that UAVs fly along a pre-planned path. The operation of an incorrectly positioned device may result not only in a failed measurement mission but also in injury, death or property damage.

2. UAV definition, classification and applications

The UAV (Unmanned Aerial Vehicle) acronym refers to a class of aircraft that can be flown without the onboard presence of aviation personnel (including the pilot). They are controlled directly from the ground using remote controller or ground station (GCS - Ground Control Station) and must be equipped with on-board control systems.

UAVs come in many different forms, shapes, and sizes. Many types of these vehicles can be distinguished such as: balloon, airship, gliders, kites, fixed wing gliders, propeller and jet engines, rotor-kite, single rotor (helicopter), coaxial rotors, quadrotors, multi-copters [8]. They range in size from Micro UAVs (weight < 2 kg) to High-Altitude Long Endurance UAVs (weight > 600 kg). They can be also categorized in terms of range, altitude, endurance, drive type, payload, dead weight and application [9]. Their important feature influencing the UAV construction is also weather and wind dependency as well as maneuverability.

There are many companies manufacturing UAVs as well as all necessary components and accessories (for example flight controllers), the most popular being DJI Innovations, Parrot, Align, 3DR Robotics, Tarot, MicroDrones, FlyTech Solutions, UAVS Poland, Taxus SI, WB Electronics, Trigger composites, SenseFly, GateWing, Trimble, Topcon, Leica Geosystems.

Unmanned Aerial Vehicles have a broad spectrum of applications. Apart from military purposes, they are used for search-and-rescue, firefighting, law enforcement, journalism, disaster response, agriculture, wild life control, real estate business and other kinds of operations [8]. A crucial characteristic of civilian UAVs is their small size and the ability to collect various data. In fact, UAVs are platforms which you can equip with different kinds of sensors, e.g. photo cameras, thermal imaging cameras, multispectral cameras or LIDAR laser scanners [10, 11]. That is why today they are used as precise, automatically controlled measurement data acquisition systems and successfully applied to environment and infrastructural resources monitoring, creating plans for property development and preparing accurate inventory of real property.

3. Description of UAV platform

The purpose of the research was to test the DJI Spreading Wings S900. It is a hexa-rotor aircraft equipped with advanced components (motors, electronic speed controllers, multi-rotor stabilization controller, gimbal and camera). The vehicle is mostly used for photogrammetric applications.

The vehicle maximum takeoff weight is 8.2 kg. According to the data provided by the manufacturer, it can fly for up to 18 minutes (used with a 6S 12000 mAh battery, on breezeless day with a payload of 6.8 kg, hovering at a height of 2 meters) [12].

The camera stabilizer (the gimbal) used in the UAV is DJI Zenmus Z15. It has built-in slip rings, preventing wire rod from winding up. It also enables free rotations for the 3 axes rotating rods. The gimbal has a built-in Z15 gimbal special servos drive module, independent IMU module and HDMI-AV module [13].

The DJI A2 multi-rotor stabilization controller is a complete flight control system for various multi-rotor platforms [14]. The flight controller supports many of the UAV’s functions, such as: control of the gimbal and the camera, the FailSafe activation, changing control mode, intelligent orientation control, low voltage protection, parachute activation. The A2 flight control system uses the controller unit as its core, which is connected with the IMU, GPS-COMPASS PRO PLUS, LED-BT-I, PMU and ESCs. The lock of UAV's height and position during flight is achieved thanks to the IMU and the GPS.

The GPS-COMPASS PRO PLUS module has a built-in GPS and a compass. The interior sensor of the A2 IMU has been upgraded comprehensively, and with high accuracy performance, large measuring range, and a unique damping design and calibration algorithm, the IMU is able to provide stable output even with high vibrations and a large movement environment. It has built-in inertial sensors and a pressure sensor for the detection of aircraft altitude.

Thanks to all the onboard systems, the hovering accuracy of DJI S900 declared by the manufacturer is (in GPS ATTI Mode): ±0.5 m (vertical) and ±1.5 m (horizontal). Additional parameters of the flight controller are: maximum wind resistance (less than 8 m/s), maximum yaw angular velocity (150°/s), maximum tilt angle (35°) and the maximum velocity of ascent/descent (6 m/s).

4. Measurement description

Two tests were carried out to assess the position stabilization accuracy of the UAV in the air, during which an operator performed basic flight maneuvers, using remote controller. The Unmanned Aerial Vehicle was operated in the automatic stabilization mode, in which the flight altitude was stabilized by means of a barometer while the position in the horizontal plane by means of a GPS receiver.

The first test was designed to determine the hovering accuracy of the UAV. It was performed in two parts which differed in duration (5 and 10 min). During the test, the UAV remained at least 40 m above the ground surface. Such measurement conditions allow the assumption that no other factor than wind thrust was affecting the device.

At the next stage (Test 2), an attempt was made to determine the accuracy of preset horizontal and vertical displacement performed by the UAV.

Fig. 1. Location and installation method of the Mini360 prism on the UAV

The position of the device in the air was determined with a Leica Nova MS50 surveying instrument equipped with servomotors and a LOCK mode which allows tracking a moving reflector. According to the manufacturer's datasheet, the MS50 working in the continuous measurement mode can record the position of a moving object at a rate of 20 Hz. During the tests, a mean data recording frequency of 5.7 Hz was obtained. The prism that was to be followed was installed on the camera stabilizer (Fig. 1), a location which enabled the determination of changes in the position of an element that is absolutely essential to the quality of collected photogrammetry data.

The measurement obtained with the MS50 was connected with two control points, whose coordinates were determined by means of RTN-GNSS technique in relation to the reference stations of MSPP network, using a GNSS Leica 1200 receiver. One of the control points was the instrument station, the other one was the reference point. Figure 2 shows the location of the instrument, reference point and UAV launch site.

During all the tests, wind speed and changes in atmospheric pressure were measured near the MS50 instrument station. The wind speed did not exceed 2.5 m/s. However, it must be noted that the measurements were taken 150÷250 m away from the UAV at a much lower height, therefore they should not be correlated with the behavior of the aircraft. The pressure did not change during testing, remaining within the accuracy limits of the gage, a Comet D4130 thermo-hygro-barometer.

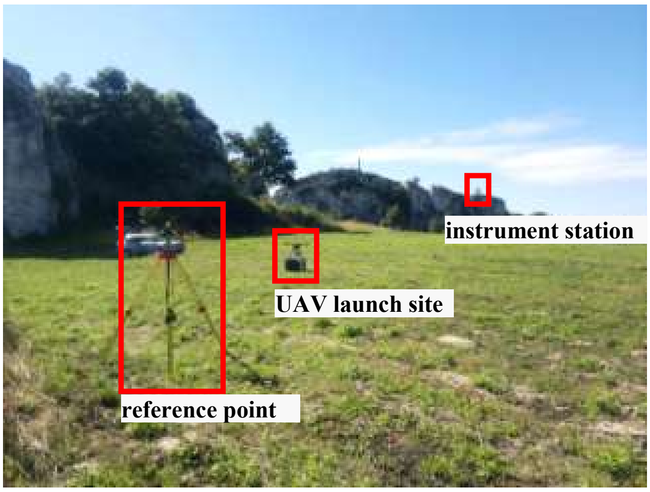

Fig. 2. Measurement set-up

5. Test results

Data analysis began with the processing of the Test 1 (UAV's hovering accuracy) measurement results, which were arranged in time ranges. The curves in Figure 3 represent changes in the position of the device along the axes of a coordinate system during a 10-minute hover. In both trials (5 and 10-minute hover), small-range, temporary changes in the position of the UAV were observed: from ca. ±0.1 m along axes X and Y to ca. ±0.5 m in the height. Depending on the conditions, the period of those changes was 10÷20 s. The obtained values reflect the ability of the device to apply corrections coming from gyro and inclination sensors installed in IMU.

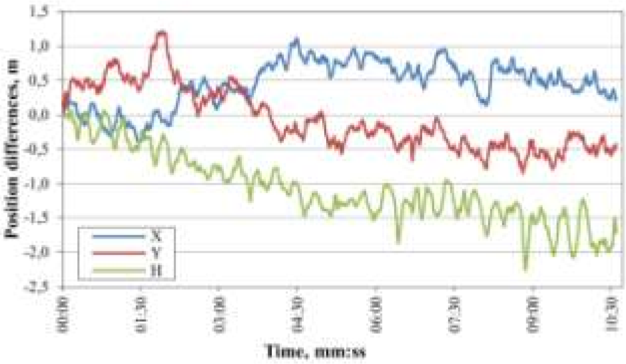

Fig. 3. Changes in UAV's position during 10-min hover

The position of the device was also observed to drift during the whole test. The drift value was determined by including simple regressions in the time ranges. Table 1 gives temporal drifts calculated for both tests, while the curves in Figure 4 represent changes in the position of the UAV after eliminating the drift. Table 2 gives the values of the device extreme positions in relation to the mean value (Δ_{max} and Δ_{min}), including the standard deviation of the calculated differences (s_Δ). These values were juxtaposed, using both raw data and data from which the effect of temporal drift had been eliminated. In the first case, the maximum differences in the position of the UAV did not exceed 2.10 m for the *X* and *Y* coordinates and 2.35 m in the height, whereas in the second they were 1.50 m i 1.20 m respectively.

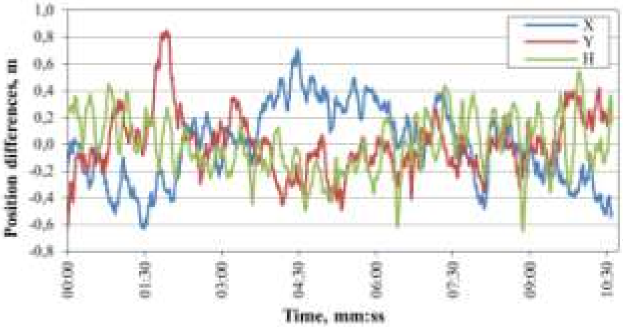

Fig. 4. Changes in UAV's position during 10-min hover after eliminating the effect of temporal drift

Eliminating drift from the data representing the position of the device in the horizontal plane does not significantly affect the difference between the extreme positions of the device. The maximum difference does not decrease by more than 25%. However, the data regarding the height of the UAV reflect a different situation. In this case, eliminating the effect of temporal drift results in a significant decrease in the difference between the extreme height values. The difference declined from 2.30 m to 1.10 m, which is equal to over 50% of the initially determined value. The drift in the horizontal plane reflects the accuracy of coordinates calculated with a GPS receiver, whereas the drift in the height should be connected with the quality of barometric data. It is worth noting that the height measurement results indicate that the UAV does not meet the position stabilization accuracy parameters as specified by the manufacturer.

Tab. 1. Calculated drift parameters of UAV

Trial	**Duration**	**Drift along the axes of a coordinate system, m/min**		
		D_X	D_Y	D_H
P1	5 min	0.069	–0.111	–0.312
P2	10 min	0.057	–0.128	–0.152

Tab. 2. Parameters showing the variations in UAV's position during Test 1

Trial	**Parameter**	**Raw data**			**Data reduced by drift**		
		***X*, m**	***Y*, m**	***H*, m**	***X*, m**	***Y*, m**	***H*, m**
P1	Δ_{max}	0.511	0.407	0.975	0.359	0.361	0.537
	Δ_{min}	-0.399	–0.654	–1.331	–0.471	–0.431	–0.486
	$\Delta_{max} - \Delta_{min}$	-0.910	–1.061	–2.306	–0.830	–0.792	–1.023
	s_Δ	0.211	0.249	0.549	0.177	0.167	0.185
P2	Δ_{max}	0.661	1.285	1.148	0.709	0.849	0.547
	Δ_{min}	-0.846	–0.776	–1.188	–0.629	–0.623	–0.648
	$\Delta_{max} - \Delta_{min}$	-1.507	–2.061	–2.336	–1.338	–1.472	–1.195
	s_Δ	0.332	0.453	0.511	0.284	0.228	0.214

The purpose of the second test was to determine the accuracy of horizontal and vertical displacement performed by the UAV over a preset interval. The device ascended from the launch site to a height of 140 m (in 20 m increments). The height difference by which the UAV was displaced was 20 m according to the indications of its onboard systems. Thanks to that, 8 measurement points, from P0 to P7, were obtained. In the horizontal plane, the device was displaced by 0 m for P1 and P7, 50 m for P2÷P5, and 70 m for P6 respectively. At each point, the UAV was left to hover for minimum 15 s in order to collect at least 60 measurement samples. Figures 5, 6 and 7 illustrate the behavior of the device in relation to each axis of the coordinate system in consecutive measurement points. In addition to that, Table 3 gives the maximum and minimum difference between the temporary position of the UAV and the mean value calculated for a given measurement point (Δ_{max}, Δ_{min}), and also the standard deviation of the obtained differences (s_Δ).

It must be noted that P0 represents the position of the UAV which is before launch and not moving. The standard deviations, smaller than 20 mm, of the coordinates defining the position of the UAV in this point can be regarded as parameters describing the accuracy of determining the point coordinates by the MS50 instrument in the analyzed test. For the stationary UAV, the parameters are at least 3 times smaller than for the hovering UAV, in whose case the standard deviation peaked at 200 mm. Therefore, it can be stated that the standard deviation of coordinates for the device in the air should be interpreted as the positioning accuracy of the UAV.

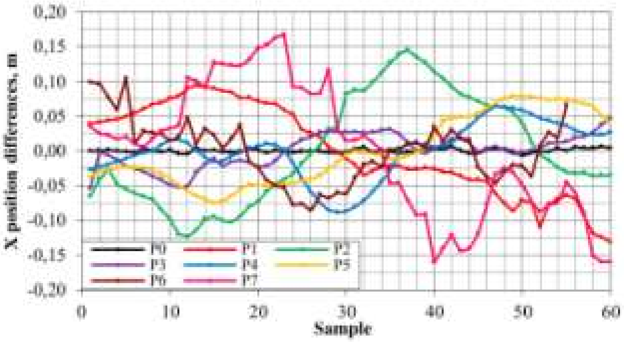

Fig. 5. Changes in UAV's position in measurement points – differences in the *X* coordinate

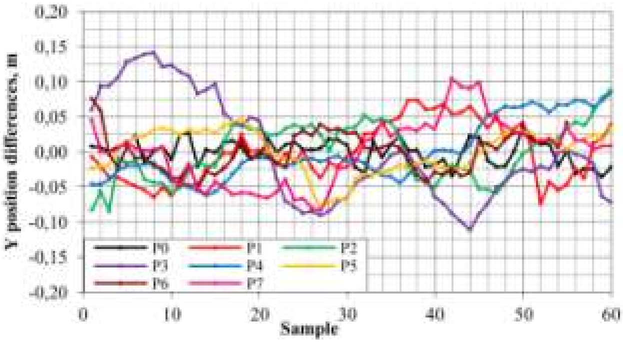

Fig. 6. Changes in UAV's position in measurement points – differences in the *Y* coordinate

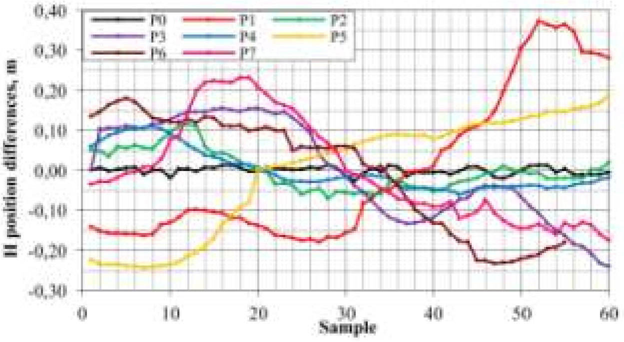

Fig. 7. Changes in UAV's position in measurement points – differences in the *H* coordinate

It must be noted that during short hovering the UAV maintains its position with an accuracy of ±0.15 m in the horizontal plane and ±0.3 m in the vertical plane. In the second test, the observation data were not reduced by the sensor drift since it was unnoticeable for such short hovering periods.

In Table 4, the pre-planned distance and elevation values are juxtaposed with those measured during the test in relation to the launch site in 7 measurement points. It is especially interesting to note that for the first measurement point (P1) the recorded elevation differed from the pre-planned elevation by 2.7 m. Such a big discrepancy is probably due to the drift of the barometric sensor. Approximately 5 minutes elapsed between powering the UAV system up and launching it, which compared to the flight duration (10÷12 minutes) is quite long. In the subsequent measurement points, the height difference can be observed to increase up to 6.60 m in the last measurement point as a result of the sensor drift. The differences in horizontal distance did not exceed 1.50 m between the launch point and the point reached in the air. Additionally, Table 4 gives the increases of the UAV displacement between consecutive measurement points. It is evident that in most cases the pre-planned height value was not reached. At each measurement step, the height increase was smaller than the pre-planned value by 0.1÷1.1 m. The obtained horizontal distances between consecutive points do not differ from the pre-planned values by more than 0.5 m.

Tab. 3. Parameters representing the variations in UAV's position in measurement points during Test 2 for short time intervals

Parameter	P0			P1			P2		
	X, m	*Y*, m	*H*, m	*X*, m	*Y*, m	*H*, m	*X*, m	*Y*, m	*H*, m
Δ_{max}	0,006	0,037	0,015	0,094	0,074	0,372	0,145	0,088	0,116
Δ_{min}	–0,007	–0,036	–0,027	–0,131	–0,075	–0,179	–0,124	–0,085	–0,071
$\Delta_{max} - \Delta_{min}$	–0,014	–0,073	–0,042	–0,226	–0,149	-0,552	–0,269	–0,173	–0,187
s_Δ	0,003	0,017	0,009	0,065	0,041	0,186	0,079	0,041	0,049

Parameter	P3			P4			P5		
	X, m	*Y*, m	*H*, m	*X*, m	*Y*, m	*H*, m	*X*, m	*Y*, m	*H*, m
Δ_{max}	0,047	0,141	0,156	0,065	0,084	0,110	0,079	0,045	0,189
Δ_{min}	–0,054	–0,112	–0,239	–0,088	–0,063	–0,061	–0,075	–0,080	–0,242
$\Delta_{max} - \Delta_{min}$	–0,101	–0,252	–0,395	–0,153	–0,147	–0,170	–0,155	–0,125	–0,431
s_Δ	0,024	0,074	0,124	0,039	0,043	0,052	0,050	0,031	0,145

Parameter	P6			P7		
	X, m	*Y*, m	*H*, m	*X*, m	*Y*, m	*H*, m
Δ_{max}	0,105	0,076	0,105	0,076	0,105	0,076
Δ_{min}	–0,086	–0,052	–0,086	–0,052	–0,086	–0,052
$\Delta_{max} - \Delta_{min}$	–0,190	–0,128	–0,190	–0,128	–0,190	–0,128
s_Δ	0,045	0,027	0,045	0,027	0,045	0,027

6. Conclusions

The proposed set of tests enabled the determination of the positioning accuracy of the whole UAV system (multirotor, camera stabilizer, onboard computer, and especially GPS receiver, compass and IMU sensor with a barometer) during hovering and performing simple flight maneuvers.

The test results allow the conclusion that the device is stabilized in the horizontal plane with up to ±1.50 m accuracy, which is consistent with the data provided by the manufacturer. The duration of the mission did not affect the results. The accuracy of the GPS receiver falls within the ranges stated in the specification of the device.

Temporary changes in the position of the device, which do not exceed 0.50 m, result from corrections introduced by the onboard computer in response to indications from the gyro and inclination sensors installed in IMU, while the temporal drift in the horizontal plane is caused by a change in the determined GPS position.

On the other hand, the device is not stabilized in the vertical plane with the accuracy specified by the manufacturer. The difference is mainly due to the drift of the barometric sensor. During short hovering it is not observable. However, this changes in the course of a whole mission, which can last several minutes or more. The barometer indications differed from the reference system values by as much as 6.64 m at the end of a 10-minute flight. This is a much larger value than the one specified by the manufacturer (±0.50 m).

Considering the measurement results, one must note that during long hovering performed by the tested device, the drift in the height, which cannot be observed in telemetric data transmitted from the UAV to the control station on the ground, must be taken into account. In all the tests, the drift had a negative value, which should be interpreted as a decrease in the flight altitude. This is a dangerous factor as it can lead to problems with maintaining proper distance from objects, e.g. during photographic inspection. During photogrammetric missions, a decrease in the flight altitude may have a negative impact on the assumed image overlap parameters [15]. However, if the device hovers for a short time to shoot a single photo or a take, the drift of the barometric sensor does not exert a significant effect.

The proposed set of tests, including the testing methodology, can successfully be applied to inspect the operation of UAVs. In order to check the operating characteristics of the whole family of DJI sensors, more devices need to be tested in various atmospheric conditions.

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Tab. 4. Planned and actual displacement of UAV in Test 2

Measurement point	Actual displacement				Planned displacement		Difference between planned and actual displacement		Displacement increases	
	D_X, m	D_Y, m	D_{XY}, m	D_H, m	D_{XY}, m	D_H, m	D_{XY}, m	D_H, m	ΔD_{XY}, m	ΔD_H, m
P1	0.243	0.373	0.445	17.255	0.000	20.000	–0.445	2.745	0.445	17.255
P2	–46.930	–19.597	50.857	37.364	50.000	40.000	–0.857	2.636	50.412	20.108
P3	–91.327	–41.955	100.503	56.724	100.000	60.000	–0.503	3.276	49.646	19.360
P4	–135.904	–65.262	150.762	75.831	150.000	80.000	–0.762	4.169	50.259	19.108
P5	–180.762	–87.855	200.981	95.248	200.000	100.000	–0.981	4.752	50.219	19.417
P6	–167.744	–213.431	271.460	114.186	270.000	120.000	–1.460	5.814	70.479	18.938
P7	–167.739	–213.332	271.380	133.363	270.000	140.000	–1.380	6.637	-0.081	19.177

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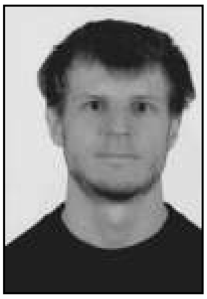

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