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The suitability of an unmanned aerial vehicle (UAV) for the evaluation of experimental fields and crops

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Abstract

The aim of this study was to assess the possibility of monitoring experimental plots by using a remote-controlled flying model adapted to perform low altitude non-metric photographs. In the first part of the paper, the advantages and disadvantages of a moto-glider construction flight as a platform were discussed. The second part presents issues associated with the acquisition and development of photographs taken with this type of construction. The study was conducted in 2008–2010 in the fields of the research farm in Wielkopolska, Poland (N 52.585°, E 16.640°), which belong to the Institute of Soil Science and Plant Cultivation, Pulawy. The photographs were taken over crops of winter wheat, spring barley and maize grown on the plots (size of 36 × 36 m), covering an area of about four hectares. The flights were made at various altitudes (20–700 m above ground level) at selected plant growth stages.

Key words: unmanned aerial vehicle, non-metric aerial photography, remote controlling, "hot patch" detection, distance.

Introduction

Digital photography performed at low altitudes allows easy usage and the acquisition of quick and low cost spatial data. This data that has undergone processing by using a geographic information system (GIS), acquires cartometric characteristics. In addition, the results of processing allow the creation of vegetation indices maps which can constitute one of the main information sources for further research (Pudełko, 2010). Vegetation index maps can be used for the analysis of agri-environmental measures (Leon et al., 2003;. Thorp, Tian, 2004; Nieróbca et al., 2008). In addition to the minimal cost of low altitude photography, the process has many other advantages such as its flexibility in scheduling the flight date as well as considering the condition of vegetation in the study area. A date for the completion of photographs and their frequency can also be adjusted to the prevailing weather conditions in the region, moreover, low and medium altitude clouds are not a barrier in performing a survey. Such opportunities are not usually available to satellite images or high resolution aerial photography. It is also possible to capture the pictures in a focused area of interest with high precision and resolution. Therefore, this low cost alternative seems to be an appropriate method for low altitude photography and is being increasingly used in research and practice.

Field experiments require cyclic supervision along with ongoing research. Monitoring ensures the proper conducting of experiments and allows the response during the occurrence that can affect the vegetation: pests, weed infestation, mechanical damage, etc. (Rydberg et al., 2007; Pudełko et al., 2008; Hunt et al., 2010). Aerial monitoring provides detailed information about the spatial variability, often invisible to ground observers. An additional advantage of this type of method of obtaining information is that aerial photos can be used as a continuous raster layer applied for spatial analysis and interpretation into a GIS (Wood et al., 2003; Bolca et al., 2011). In the case of experiments conducted on mosaic soils, high-resolution aerial photographs are the only effective way to assess the impact of soil conditions (Pudełko et al., 2012). This also applies to experiments conducted on small plots.

Low altitude flying platforms are increasingly being used as a tool to take pictures. Agricultural and environmental studies have several alternative constructions: balloon (Jensen et al., 2007), blimp (Inoue et al., 2000), model airplanes (Hunt et al., 2005; Rydberg et al., 2007), model helicopters (Sugiura et al., 2005). The development of new technologies is mainly due to the miniaturisation of electronics which allows the light-weight models. It is also characterised by ease of flying control and camera stabilisation. It is equipped with electronics designed for precision navigation: autopilots (Wendel et al., 2006), video camera and/or GPS signal transmitted from the radio modem (Jensen et al., 2007). The usefulness of flying platforms in field studies is determined mainly by the simplicity of operation by a person who is not a professional modeller.

Materials and methods

For the research, a remote-controlled model moto-glider that allows the execution of visual flight was used (Fig. 1). For images, a “Sony DSC F828” camera with a resolution of 8 Mpixels was placed on the moto-glider. The camera rack allows semi-vertical photographs to be taken. The acquisition of a vertical direction (nadir) of image axis is also affected by the state (stability) of the flight. A rapid flight into the wind or the impact of rising currents on the swinging model causes a momentary deflection of the camera’s field of view.

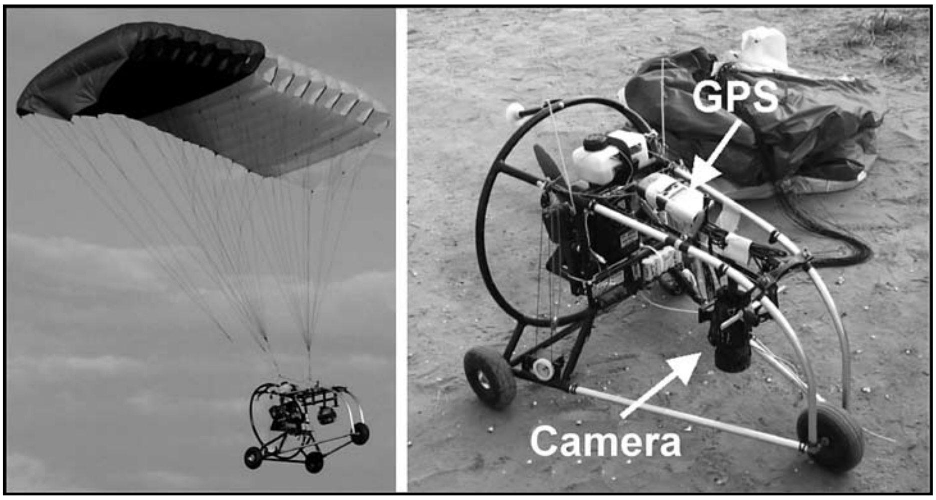


Figure 1. Unmanned aerial vehicle – moto-paraglider model (le drone Pixy, ABS)

The study was conducted over the fields of the research farm in Wielkopolska (N 52.585°, E 16.640°), which belong to the Institute of Soil Science and Plant Cultivation. This region is characterised by little rainfall and a large mosaic of soils. The photographed plots occupied an area of approximately 4 ha of various altitudes (20–700 m above ground level). The field’s terrain is characterised by a flat surface on which the local denivelations do not exceed 2–3 m per 50 ha field. For the orthorectification of selected pictures the white crossed markers were placed on the ground. The coordinates for the centre of the cross were determined by measuring with GPS (“Trimble ProXRS”) working in a phase mode. Data from the mobile receiver were corrected in post processing with the second receiver working as a base-station. So the resulting set of 40 points was used in the orthorectification process as ground control points (GCPs). The digital photos were subject to geometric correction and content analyses by the use of the *Erdas Imagine* (ERDAS Field Guide, 2002).

Results and discussion

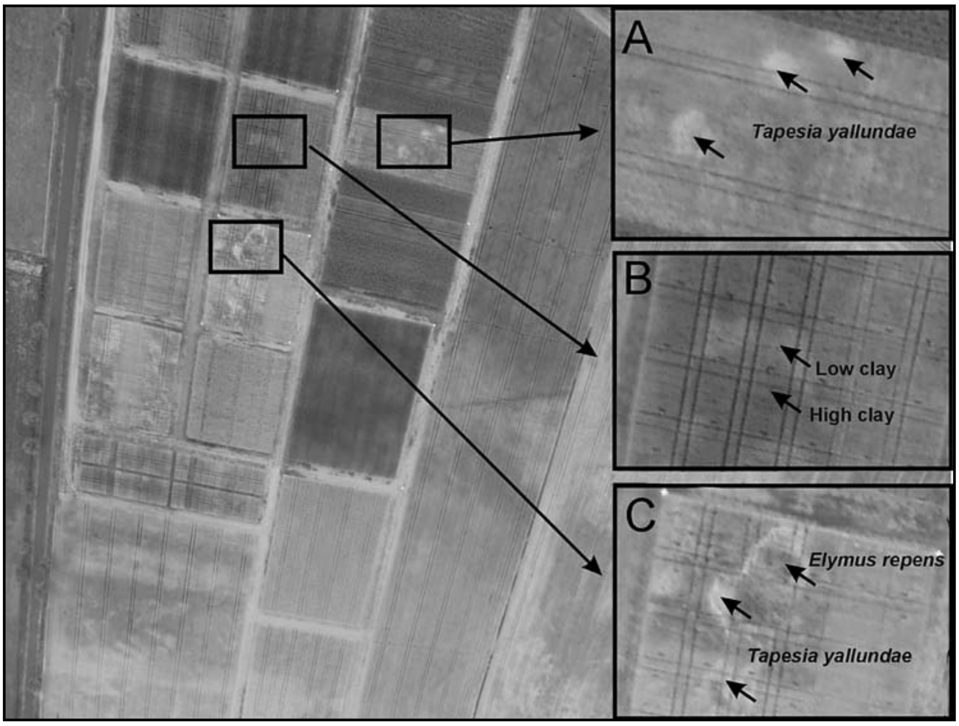
The assessment of the unmanned aerial vehicle (UAV) properties. UAVs used for taking photographs are based on a moto-paraglider construction. This design compared to the models of aircraft can operate in a lower altitude and it is easy to remote control. The takeoff and landing performance of moto-paragliders is very good, allowing easy operation on almost any terrain. Depending on the strength of the wind, the model begins its flight within a few meters and lands by a parachute, after changing the relative position of the wing attachment. These features allow you to quickly master the flying skills for a potential user. The technical characteristics of the model: weight 6 kg, optimum load weight 2–3 kg, cruising speed of about 15–20 km h^{-1}, flight time about 40 min. The ceiling altitude attainable by the described model is about 1500 m, and a range of about 3–4 km.

Because of its design, the model has limitations due to the weather conditions. The maximum wind speed allowing obtaining the resultant forward speed should be up to 5–6 m s^{-1}, therefore altitude gradient of wind speed should be taken into consideration. During the day the best conditions for flight are in the morning or late afternoon, which due to the angle of the sun’s rays are not always conducive to taking photos. The disadvantage is the high volatility of the model in flight and the difficulty in maintaining a straight flight.

The large capacity (ratio of the mass model to the payload) is the unquestionable advantage of this design in comparison with other models of aircraft. Retrofitting models with a radio modem transmitting data from GPS and miniature cameras, allows increasing the precision of navigation and shooting at moments of stable flight.

Interpretation of photographs. The photographs taken from various altitudes make it possible to extract information about the spatial variability within the experimental plots. Determining the differences in canopy structure for a single experiment may indicate the occurrence of adverse factors (weeds, plant diseases, damage from hunting, etc.), which may affect the results. An example is shown in Figure 2, which illustrates the detection of places where the differences are visible within the structure of the canopy plot. The photograph was taken on 03 07 2009 in the late afternoon. Ground observations indicated the presence of weeds and disease outbreaks in different parts of the plot.

The small size of individual plots (36 × 36 m) determines a need to obtain high-resolution photographs, which can be successfully achieved by using UAVs. In the case of the highest-resolution photographs made at an altitude of 10–50 m, this is not necessary, because of their sensitive orthorectification that can be identified with a high accuracy in estimating their location directly, by comparing the pictures with the borders of plot (Fig. 3).



Note. A, C – eyespot (*Tapesia yallundae*) within spring barley canopy and intensity of couch grass (*Elymus repens*, C only), B – winter wheat, influence of soil mosaic. The photo was taken on 03 07 2009, before sunset.

Figure 2. "Hot patch" detection in spring barley and winter wheat

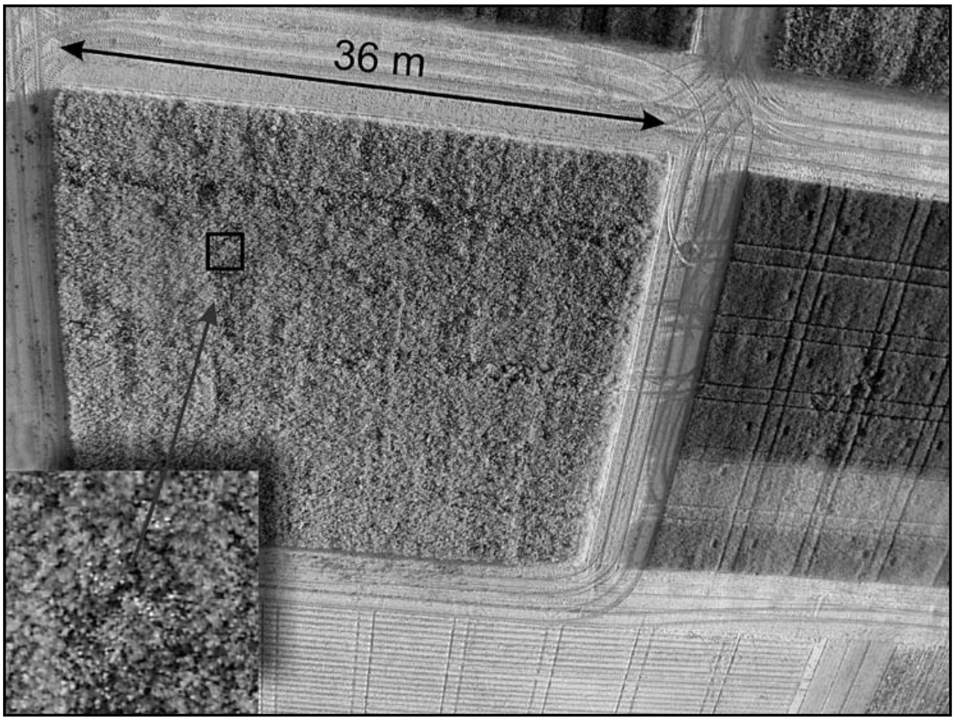
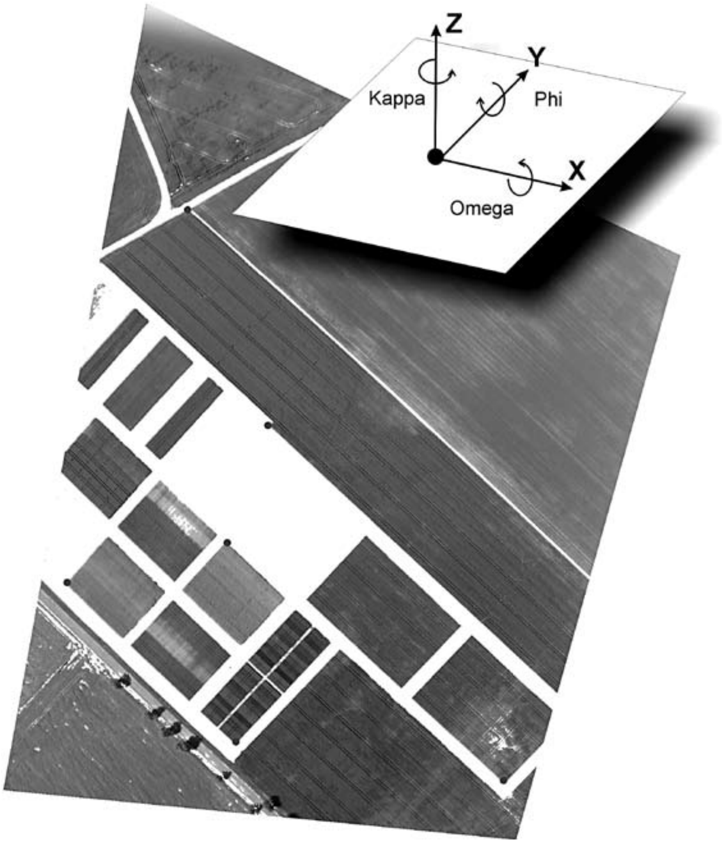


Figure 3. Sample of very low altitude photography

Orthorectification is indicated for photos taken on a smaller scale for larger fields. The advantage of orthorectification is the ability to turn these photographs into a GIS database so that it becomes possible to analyse metrically (estimating distance and surface) and temporal changes (Fig. 4).

The geometric quality assessment of the image. The results are shown in the example of three images that were orthorectified using the selected parameters. Therefore, the location of points (GCP) and precise determination of their coordinates is the most important aspect of the process of geometrisation images, four attempts were made to select the best one, carrying the smallest error of the geometric model. The first attempt assumes the use of six points on the coordinate plane X, Y, and possibly evenly distributed on the photo. The second attempt uses the same points, which introduce an additional attribute of height. The third attempt increased the number of points to ten while maintaining an even distribution on the image. In the fourth attempt, this uses all possible points of the image.



Note. Geometrical deformations caused by non-vertical camera orientation: omega – 10.3°, phi – 24.3°. The photo was taken 420 m above ground level. Dots mark GCPs location.

Figure 4. Photo after orthorectification based on the six ground control points (GCPs)

Table 1 shows a comparison of the difference between the obtained geometric models. The root mean square error (RMSE) value is expressed in pixel size, where the size is different in every picture. It depends on the height and angle (roll and pitch) at the moment of shutter release. Indicative ranges of pixel size are from ~8 to 15 cm.

Table 1. The dependence of geometry images error from the used points

No.	Photo ID	Number of GCPs	RMSE – in pixel size
1.	1	6	6.77
2.	1	6 – with height attribute	6.14
3.	1	10	5.21
4.	1	33	5.67
5.	2	6	6.22
6.	2	6 – with height attribute	6.05
7.	2	10	7.35
8.	2	22	6.69
9.	3	6	6.93
10.	3	6 – with height attribute	6.38
11.	3	10	6.90
12.	3	22	6.82

The results presented in Table 1 confirm the beneficial effect of the introduction of an attribute, which improves the accuracy to about 10%. Further improvement of the orthorectification quality can be achieved by introducing more points. This is evident especially for the first picture (Table 1, Photo ID = 1), where the error was reduced by about 25% after the introduction of additional 4 points (compared with 6 points with no height attribute). In other cases, the RMSE increased (Table 1, Photo ID = 2) or slightly decreased (Table 1, Photo ID = 3).

The orthorectification process changed the geometric orientation of each photo, calibrating it to the selected plane coordinate system (UTM, zone 34). In any case, the optimal pixel resolution can be taken at 15 cm. A large swing in the camera when shooting resulted in trapezoidal distortion of the geometry of images (Fig. 4). This inclination is a component of the market in an axis parallel to the flight (angle omega) and the axis perpendicular to the flight and ground parallel with the plane (angle phi). The current experiment did not confirm the relationships between the optical axis deviation from the vertical images and the accuracy of the orthorectification. The smallest model geometry errors and actual errors were obtained for data presented on Figure 4, which was taken at an angle phi: 24.3 degrees and tilt "on the wing" for omega: 10.3 degrees (Table 2). The actual error of orthorectification was estimated for each image by distance between the GPS coordinates of reference points and coordinates of the image visible in the picture (Table 2). The obtained result, confirms the accuracy of orthophotos sub-meter received under non-metric and non-vertical photography with a resolution of 3264 × 2440 pixels with a altitude of about 400 m.

Table 2. The difference in distance between reference points and their image in the photography after orthorectification (columns 1 and 2) and summary of the main parameters of the flight at the time of taking photography (columns 3, 4 and 5)

Photo ID	Max error (m)	Mean error (m)	Altitude	Omega angle	Phi angle
	1	2	3	4	5
1	1.2	0.4	388	10.3	24.3
2	1.4	0.7	398	9.3	14.2
3	1.5	0.7	415	−6.0	−16.1

The study was conducted from 2008 to 2010. During this period many orthorectification processes were done. All results confirm the accuracy shown above.

In comparison to the results presented by other authors (Rydberg et al., 2007), the UAV (moto-paraglider) that was used allows obtaining high quality data. This is because the camera has a very good optics system and large image sensor (digital single-lens reflex, DSLR). These kinds of devices are characterised by greater weight than small cameras which are typically mounted onto model radio-controlled (RC) planes. Moreover, moto-paraglider can be used for taking precise pictures at a very low altitude which is quite impossible for model RC planes (Hunt et al., 2005), and in the case of model helicopters they demand an experienced operator which also limits their usage (Sugiura et al., 2005). The results confirm that using the UAV for collecting non-metric photos also allows obtaining spatial error with an accuracy within one metre for captured image data.

The presented UAV is sufficient equipment for monitoring experimental field conditions. However, its application for monitoring large fields, due to its construction type, could be ineffective. Looking at the current rapid development of the UAV technology, one can suppose that in the near future there will be more common constructions based on multi-rotor systems. They offer the advantages by combining the designs of helicopters (vertical take-off and hovering), aircraft (flight speed) and motor-paraplanes (ease of remote control).

Low altitude photography has advantages over high altitude air photography and satellite methods, as it is not limited in its usage due to cloud cover present in the high and middle layers of the atmosphere.

Conclusions

The evaluation of the unmanned aerial vehicle (UAV) properties and evaluation of the data quality allows formulating the following conclusions:

1. The UAV moto-paraglider construction stands out from other types of UAVs by ease of piloting and operation. However, its structure is sensitive to weather conditions which predispose them to carry out short and low level flight. The main difficulty in the use of the present flying model is wind speed and thermal currents that occur most frequently on a summer afternoon. Therefore, the most appropriate times of the day to perform flights are morning and afternoon.

2. The large mass of the load in relation to the total weight permits the use of high quality cameras, which enable performance of high-resolution photography.

3. The interpretation of the images enables obtaining data on spatial variability of the study area, which is not always achievable using terrestrial observation methods.

4. Orthorectification of images allows for orthophotomap with a precision sufficient for agricultural and environmental research.

All the above listed advantages authorise us to recommend this type of construction for use in agricultural research and in precision agriculture. An additional advantage of UAVs is the low cost of obtaining aerial photographs, and operation and maintenance.

Indications for future research:

1. The need to replace the gravity fixing of telescopic camera by a gyroscope, which enables better stabilisation of the camera.

2. Camera calibration matrix to estimate the distortion photos, which should further improve the result of orthorectification.

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Bandymų laukų stebėjimas, naudojant nepilotuojamą motorinį sklandytuvą

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Santrauka

Tyrimo tikslas – įvertinti galimybę stebėti bandymų laukus, naudojant per atstumą valdomą skraidantį modelį, pritaikytą nedideliame aukštyje daryti nemetrines nuotraukas. Straipsnio pirmoje dalyje aptarti motorinio sklandytuvo konstrukcijos privalumai ir trūkumai. Antroje dalyje aptartos problemos, susijusios su tokios konstrukcijos sklandytuvo padarytų nuotraukų kaupimu ir panaudojimu. Tyrimas atliktas 2008–2010 m. Lenkijoje, Vielkopolskos bandymų ūkio laukuose (N 52.585°, E 16.640°), priklausančiuose Pulavų valstybiniam dirvotyros ir augalininkystės institutui. Fotografuoti žieminių kviečių, vasarinių miežių ir kukurūzų pasėlių 36 × 36 m dydžio laukeliai, užimantys 4 hektarų plotą. Skrydžiai atlikti įvairiuose (20–700 m) aukščiuose tam tikrais augalų vystymosi tarpsniais.

Reikšminiai žodžiai: nepilotuojamas skraidantis prietaisas, nemetrinė aeronuotrauka, nuotolinis valdymas, „karštų laukelių“ nustatymas, atstumas.