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TECHNICAL NOTE

A flexible unmanned aerial vehicle for precision agriculture

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Abstract An unmanned aerial vehicle ("*VIPtero*") was assembled and tested with the aim of developing a flexible and powerful tool for site-specific vineyard management. The system comprised a six-rotor aerial platform capable of flying autonomously to a predetermined point in space, and of a pitch and roll compensated multi-spectral camera for vegetation canopy reflectance recording. Before the flight campaign, the camera accuracy was evaluated against high resolution ground-based measurements, made with a field spectrometer. Then, "*VIPtero*" performed the flight in an experimental vineyard in Central Italy, acquiring 63 multi-spectral images during 10 min of flight completed almost autonomously. Images were analysed and classified vigour maps were produced based on normalized difference vegetation index. The resulting vigour maps showed clearly crop heterogeneity conditions, in good agreement with ground-based observations. The system provided very promising results that encourage its development as a tool for precision agriculture application in small crops.

Keywords High resolution images · Normalized difference vegetation index · Multi-spectral images · Vigour maps · Vineyard

Introduction

Nowadays, most precision agriculture (PA) research is oriented towards the implementation of new sensors and instruments, able to remotely detect crop and soil properties in quasi-real time. Whereas the spatial resolution of some satellite sensors, such as Ikonos and Quickbird has been improved recently, nevertheless some major concerns still depend on the difficulty to take repeated measurements during the crop cycle (Moran et al. 1997; Yang et al. 2006).

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A solution to overcome these problems is the use of airborne remote sensing which allows very high spatial resolution, (of the order of a few centimeters), and choice of independent timing of aerial passes. The latter fact avoids inadequate frequency of satellite surveys or disturbing cloud cover conditions. However, some specific limits of airborne remote sensing are high operational costs which make it economically profitable only over large areas, and the lack of time flexibility associated with the scheduling of flight plans.

In the last decade, the development of unmanned aerial vehicles (UAV) platforms, characterized by small size has offered a new solution for crop management and monitoring, capable of timely provision of high resolution images, especially where small productive areas have to be monitored (Lelong et al. 2008).

For these reasons, it is believed that a UAV with these characteristics could be suitable for vineyard management where very flexible monitoring with typically less than one week notice is needed. This is especially true in a region like Tuscany (Central Italy), characterized by a fragmentation of the properties into small units up to 5 ha, by wide diversity in topography and climatic conditions and by large differences in wine production quality (Matese et al. 2009).

Such variability is directly correlated with the annually stored biomass—created by photosynthesis—per surface unit, generally referred as vigour (Bramley et al. 2011; Goulet and Morlat 2011; Huglin and Schneider 1998). Therefore, it is clear that vigour maps derived from vegetation indices such as Normalized Difference Vegetation Index (NDVI), might provide useful information to viticulturists to increase the oenological potential of the vineyard (Berni et al. 2009; Costa-Ferreira et al. 2007, 2009).

In this work, the aerial platform “*VIPtero*”, a flexible and completely customizable UAV system, capable of acquiring high resolution multi-spectral images particularly suited for precision agriculture applications over small crops is described. The vegetation indices obtained from UAV images are in excellent agreement with those acquired with a ground-based high-resolution spectroradiometer. Finally, some results of imaging analysis over an experimental vineyard, resulting from the flight campaign with “*VIPtero*” are shown.

Materials and methods

Hardware setup

The UAV platform “*VIPtero*” is a modified Mikrokopter Hexa-II (HiSystems GmbH, Moomerland, Germany), an open-source project that is available with pre-assembled flight and brushless control boards, and optional 3-axis magnetic compass and a global positioning system (GPS) unit. The “*VIPtero*” is a six-rotor aerial platform capable of vertical take-off and landing and flight autonomously to a user-defined set of waypoints. The effective payload is of around 1 kg with 10 min of continuous operation.

The Hexa-II was further equipped with an EagleTree telemetry kit, a custom made First Person View flight system (Eagle Tree Systems LLC, Bellevue, WA, USA) and a “black box” with autonomous power supply, GPS receiver and a global system for mobile communication (GSM) modem for the recovery of the platform in case of any malfunction of the navigation system.

The “*VIPtero*” has an underslung universal camera mount, compensated for pitch and roll by hi-speed tilt servos directly operated by the flight control board (FlightCTRL). This was customized including a 3-axis elastic suspension to decouple the camera-UAV system and dampen the high-frequency vibration induced by the rotating propellers. The overall cost of the system components is around 4 000 €.

The FlightCTRL, the main board responsible for the actual flight of the mikrokopter, is built around an ATmega1284P microcontroller (Atmel Corporation, San Jose, CA, USA) and communicates to the six brushless controllers via a bi-directional two-wire serial bus (I2C bus). It integrates a pressure sensor and 3-axis accelerometers to calculate and align with earth gravity. An additional navigation control board (NaviCTRL) equipped with an ARM9 microcontroller (Atmel Corporation, San Jose, CA, USA) and MicroSD card socket for waypoint navigation data storage is also present. With its 3D digital compass, the rotation along the z-axis (yaw) is monitored and, together with the LEA-6 GPS module (U-blox AG, Thalwil, Switzerland) with a circular error probable accuracy of 2.5 m, it permits various degrees of autonomous flight.

At present, the system is used to hold the "*VIPtero*" at fixed position in space, to eliminate the yaw effect on motion control direction and to implement autonomous waypoint flight and a "back-home" feature.

The Hexa-II implements six ATmega8 control boards (Atmel Corporation, San Jose, CA, USA) that provide the required triphasic alternating current to the brushless motors and can accept throttle values very rapidly (with a typical response of less than 0.5 ms).

The Hexa-II is equipped with a 4-cell 3300Ah 14.8 V Lithium polymer battery (Shanhai Danlions International Co., Shanghai, China) that gives a theoretical flight autonomy of 10 min. The UAV is controlled with a 2.4 GHz duplex transmitter (JETI model s.r.o., Příbor, Czech Republic), a full channel hopping spread spectrum system that continuously transmits information to the controller including: battery status, power consumption, engine status, height and horizontal distance from take-off point. The UAV can also receive firmware updates, waypoints input and display status information via Bluetooth protocol using the Koptertool software provided by HiSystems GmbH.

The camera used in this study was a Tetracam ADC-lite camera (Tetracam, Inc., Gainesville, FL, USA) equipped with a 3.2-megapixel CMOS sensor (2 048 × 1 536 pixels). The camera weighs 200 g and has remote power and display features for optimized placement on UAV platforms. The primary use of this product is to record vegetation canopy reflectance; the resulting image is suitable for derivation of several vegetation indices (NDVI, Soil Adjusted Vegetation Index, canopy segmentation and Near Infrared/Green ratios). Images are recorded in the visible red and green and near infrared (NIR) spectrum with nominal wavelengths of 520–600, 630–690, and 760–900 nm, respectively. The 3.2-megapixel ADC fitted with an 8.5 mm lens has a field of view of 43° and is able to achieve a 0.056 m/pixel ground resolution at a flight height of 150 m.

The instrument used for NDVI validation is a FieldSpec Pro spectroradiometer (ASD Inc., Boulder, CO, USA). The overall range of the spectroradiometer is 350–2 500 nm acquired by three internal sensors with high signal-to-noise ratio to measure radiation in UV/VNIR (350–1 050 nm), SWIR1 (900–1 850 nm) and SWIR2 (1 700–2 500 nm). The spectral resolution of the spectrometer is 3 nm at 700 nm and 10 nm at 1 400/2 100 nm. Integration time is set automatically for each of the three arrays to optimize incoming radiation levels in all three regions.

Image processing

The raw multi-spectral images provided by the Tetracam need to undergo a series of steps in order to provide a vigour map. The first step in the processing chain was the ortho-rectification of the images. This was performed by means of a digital elevation model (DEM) of 5 × 5 m resolution derived by digital 1:5 000 contour maps of Laboratorio di Monitoraggio e Modellistica Ambientale per lo Sviluppo sostenibile (LaMMA), with ENVI 4.5 (Exelis visual information solutions inc., Boulder, CO, USA). The images were then geo-referenced by a set of ortho-photos with a ground resolution of 0.5 m provided by the cartographic service of Regione Toscana and radiometrically corrected to convert the digital number of each pixel (brightness value) first into spectral radiance and then into reflectance as described in Goward et al. (1991). Afterwards the NDVI was computed by the equation:

$$\mathrm{NDVI} = (R_{\mathrm{NIR}} - R_{\mathrm{RED}}) / (R_{\mathrm{NIR}} + R_{\mathrm{RED}}) \tag{1}$$

where, R_{NIR} and R_{RED} are the reflectance in near infra-red and red bands, respectively (Rouse et al. 1973). NDVI maps were subsequently processed with ArcGIS 9.3 (ESRI inc., Redlands, CA, USA) in order to separate canopy pixels from soil pixels (Delenne et al. 2010). Finally, vigour maps were created propagating canopy values into the inter-row space with the kriging method (Oliver and Webster 1990), and assuming the correspondence between NDVI and vigour (Costa-Ferreira et al. 2007; Fiorillo et al. 2009).

Results

As a preliminary step, NDVI values acquired by the ADC-lite camera mounted on "*VIPtero*" were compared to ground-based NDVI values measured with the FieldSpec Pro spectroradiometer to verify the precision of the ADC system. The field validation was performed on May 24th, 2011, comparing data for 5 targets placed on a grass meadow in two different sets of measures, at 11:30 AM and 12:30 PM. For each target, 3 values were acquired and averaged with the spectroradiometer. At the same time, an image was taken by "*VIPtero*" from a height of 5 m. The spectroradiometer values were correlated with the NDVI values obtained from an average over the area of the picture targets. Figure 1 shows

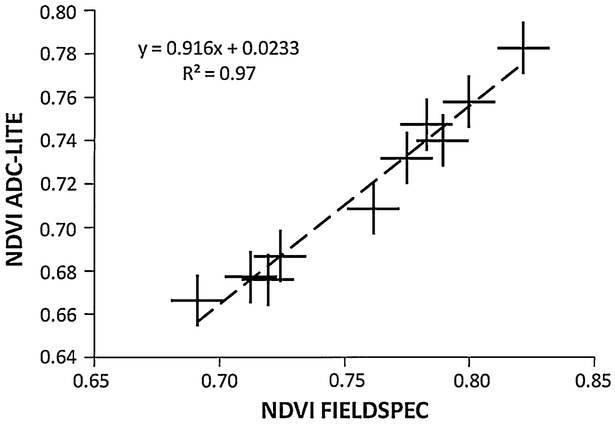

Fig. 1 Linear regression between NDVI values measured with the ADC-LITE images and ground based measurements by FIELDSPEC spectroradiometer. *Errors bars* represent the standard errors calculated from the spectroradiometer measurements and the pixel values (ADC-LITE images) corresponding to each target area, the *dotted line* represents the 1:1 relation

the high correlation ($R^2 \approx 0.98$) between airborne and ground-based measurements of NDVI values.

The UAV flight campaign was made at the experimental vineyard of Monteboro (Empoli, FI 10°55′01″E, 43°41′28″N) on May 27th, 2011. This vineyard, located in a hilly environment, had a visible intra-field vigour variability that suited perfectly with the aims of this study, despite its small size of about 0.5 ha.

The GPS position of the vineyard centre was transmitted to UAV naviCTRL via Bluetooth (by the Koptertool software), and after a manual take-off at 13:05, "*VIPtero*" flew autonomously to the predetermined waypoint at 150 m height. The UAV was left in place for 5 min and the camera set on continuous shooting mode, with one picture taken every 5 s. The analysis of the GPS registered data confirmed that "*VIPtero*" maintained its position in space with good precision during the image acquisition step, the flight correction of the platform in the light wind of the day appeared gradual and smooth. The UAV then returned autonomously to vertically above the starting position at 25 m height and was landed manually. The overall flight took 7.5 min.

During the flight, the "*VIPtero*" had an average power consumption of 350 W which, allowing for a 20% emergency battery capacity, should permit up to 9 min of operation.

A preliminary analysis of the 63 images taken was done to select the picture to be used in the further steps. This was necessary because some of them were affected by a distortion of the straight lines of the canopy, a documented graphical artifact induced by the vibrations of the camera and typical of rolling shutter CMOS systems (Liang et al. 2008).

On the selected image, an NDVI map and a five-class vigour map were produced. Figure 2 shows a clear gradient in vegetation vigour. This confirmed the empirical evaluation by the local viticulturist who divided the vineyard into two halves: the eastward needing different management and producing a better wine than the westward (personal communication). The map allowed identification of a finer and clearer subdivision in units that are homogeneous with respect to the growth level and, consequently, could be a valuable tool for precision viticulture.

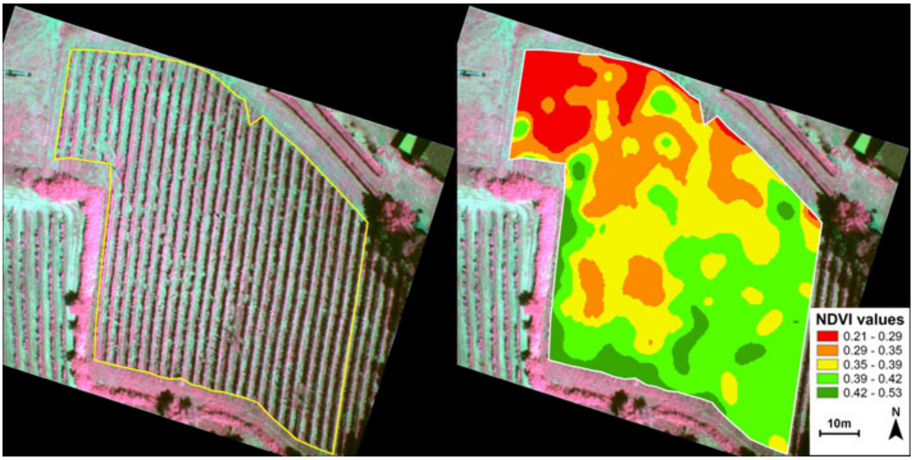

Fig. 2 Multi-spectral images of the Monteboro vineyard (*left*) false color image at 5 cm of spatial resolution and (*right*) classified NDVI based vineyard vigour map

Discussion

"*VIPtero*" showed a good ability to perform the required tasks, it was able to fly precisely over a fixed point in space and to maintain the desired position for a definite time, overcoming the common problem of coupling the images taken with the flight path (Gay et al. 2009), while not requiring the use of complex GPS-controlled camera triggers (Lelong et al. 2008). This ability, together with the possibility of giving more waypoints to the NaviCTRL, could lead to an easier mosaicing of several images (Berni et al. 2009). Moreover, because the UAV weighs less than 7 kg and flies within sight of the operator, it is subjected to minimal airspace limitations and it is free from the constraints of scheduled flight plans, making it a very flexible remote sensing system when dealing with small crops. One of the main problems that still need to be addressed is the mechanical vibration damping system of the camera, which limits the number of "good" images and the possibility of going beyond 2–3 waypoints per flight.

Although the possibility of using UAV in PA has been tested by several authors (Berni et al. 2009; Herwitz et al. 2004). This is the first example of UAV based NDVI and vigour mapping over vineyards in Italy. Since several works have demonstrated that grape quality parameters are inversely correlated to vineyard vigour (Johnson et al. 2001; Lamb et al. 2004), vigour maps appear to be an appropriate tool for intra-block vineyard management and precision viticulture.

Conclusions

Technology applications in the agricultural sector may significantly improve input efficiency, environmental sustainability and, not least, farmer income. However, these new instruments might be common tools in a farmer's assets only if they are user-friendly, automatic and economically affordable. The "*VIPtero*" platform potentially meets these aims, since it is relatively cheap and able to complete autonomously almost all the flight steps and image acquisition processes. Improvements are needed regarding flight length, camera vibration image acquisition and provision of the possibility of autonomous take-off and landing. However, preliminary results are encouraging and further miniaturization of sensors and detectors could greatly enhance the potential of this platform.

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