

Development of a UAV system for VNIR-TIR acquisitions in precision agriculture

Misopolinos L.^a, Zalidis Ch.^a, Liakopoulos V.^{a,b}, Stavridou D.^a, Katsigiannis P.^a, Alexandridis T.K.^c, Zalidis G.^{a,c}

^a Interbalkan Environment Center, 18 Loutron Str. Lagadas, Greece; Tel.: +30 2394023485; E-mail: info@i-bec.org; ^b Aeroview, 30 Makedonias Str. Xanthi, Greece; Tel +306978116071; E-mail: info@aeroview.gr; ^c Aristotle University of Thessaloniki, Faculty of Agriculture, Thessaloniki, Greece; Tel +30 2310 991777; E-mail: thalex@agro.auth.gr

ABSTRACT

Adoption of precision agriculture techniques requires the development of specialized tools that provide spatially distributed information. Both flying platforms and airborne sensors are being continuously evolved to cover the needs of plant and soil sensing at affordable costs. Due to restrictions in payload, flying platforms are usually limited to carry a single sensor on board. The aim of this work is to present the development of a vertical take-off and landing autonomous unmanned aerial vehicle (VTOL UAV) system for the simultaneous acquisition of high resolution vertical images at the visible, near infrared (VNIR) and thermal infrared (TIR) wavelengths. A system was developed that has the ability to trigger two cameras simultaneously with a fully automated process and no pilot intervention. A commercial unmanned hexacopter UAV platform was optimized to increase reliability, ease of operation and automation. The designed systems communication platform is based on a reduced instruction set computing (RISC) processor running Linux OS with custom developed drivers in an efficient way, while keeping the cost and weight to a minimum. Special software was also developed for the automated image capture, data processing and on board data and metadata storage. The system was tested over a kiwifruit field in northern Greece, at flying heights of 70 and 100m above the ground. The acquired images were mosaicked and geo-corrected. Images from both flying heights were of good quality and revealed unprecedented detail within the field. The normalized difference vegetation index (NDVI) was calculated along with the thermal image in order to provide information on the accurate location of stressors and other parameters related to the crop productivity. Compared to other available sources of data, this system can provide low cost, high resolution and easily repeatable information to cover the requirements of precision agriculture.

Keywords: unmanned aerial vehicle, precision farming, robotic helicopter, visible-near infrared, thermal infrared

1. INTRODUCTION

Precision agriculture (PA) is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. Although commercially practiced only since the 1990s, it is considered as one of the top ten revolutions in agriculture¹. PA practices require higher spatial and temporal resolution information on the crop-soil-water status of a given field than conventional agriculture. Thus, remote and proximal sensing techniques have been developed to account for these needs. Recent technological development in the field of remote sensors and unmanned aerial vehicles (UAV) has been proven to be a power tool for the purposes of PA, providing low cost tools that achieve highly accurate results with increased usability. A significant load of effort by several developers has been given during the last few years towards the optimization of UAV systems.

Primicerio et al.² introduced a UAV as a flexible and powerful tool for site-specific vineyard management. It utilized a multispectral camera for vegetation canopy reflectance recording, in order to produce vigour maps that clearly showed crop heterogeneity conditions; in good agreement with ground-based observations. The need for further development was noted, in order to achieve longer flight duration and thus cover larger fields, to eliminate the camera vibration for higher image clarity, and to achieve platform autonomous take-off and land. Another important issue was the miniaturization of the camera sensors that would potentially increase flight time and usage of multiple sensors. In order to develop low-cost agricultural remote sensing system based on an autonomous unmanned aerial vehicle (UAV) Xiang

and Tian ³ introduced a helicopter platform equipped with only a multispectral camera and autonomous pilot system to monitor turf grass herbicide applications. The system was based on an easily transportable helicopter platform and the whole autopilot system was custom developed by the team, thus requiring a high level of specialization. Another issue noted was the difficulty to operate and maintain this system powered by an internal combustion engine, as well as the higher cost than the equivalent electric motor systems. Nebikera et al. ⁴ presented a prototype light-weight multispectral sensor for micro UAV used in for assessing crop health. Turner et al. ⁵ developed a UAV capable of collecting very high resolution visible, multispectral and thermal imagery for precision viticulture. They produced Digital Surface Models (DSMs) of the vineyards, soil moisture map for assessment of irrigation efficiency, and vegetation indices for assessment of vines vigour and health. It is pointed out that they used the two sensors (multispectral and thermal) individually due to multicopter payload limitation.

In order to summarize, the main problems identified in literature are the flying duration limit, payload restriction, image distortion due to wide angle viewing, photogrammetric distortions due to low overlap, image blurring due to high flying speed, image differences due to changing illumination conditions in the same flight. Thus, there is space for further improvement of such systems, taking into consideration the above mentioned problems. The aim of this work is to present the development of a hexacopter UAV platform for autonomous, simultaneous triggering of two cameras, covering the target field in as few flights as possible, in a speed acceptable by the sensors on board.

2. MATERIALS AND METHODS

2.1 Hexacopter UAV platform

The hexacopter UAV platform (Figure 1) that was used to accommodate the necessary equipment is a hexacopter UAV platform, which was an assembly of different parts. The main frame was the Vulcan Hexa and the technical specifications are presented in Table 1. The flight controller installed was the WooKong-M, a complete flight control system for all commercial, industrial and professional multi-rotor platforms. It gives the user the option of the following functions: (i) pre-program a flight including up to 50 waypoints with custom parameters for speed, altitude, type of turn between waypoints, and even custom robotic servo actions to be completed at each waypoint, (ii) automatic take off, complete the entire mission, return home, and land itself at the location it took off, (iii) several fail-safe measures to account for human errors like excessive flight duration or an altitude below ground level, and (iv) flexibility to change the flight parameters on the fly, during the actual flight. This flight controller was equipped with a ground station, a graphical user interface for the PC, in order to control through telemetry all the flight parameters.

Table 1. Vulcan Hexa multicopter technical specifications.

Technical information Vulcan Hexacopter UAV platform	
Type	Multicopter
Diameter	800mm
Weight	5kg
Payload capability	4 Kg
Voltage	22V
Battery capacity	16.000 mah
Flying time	15min
Maximum operation altitude (water level)	2500m
Waypoints	50
Fail safe function	Return to home and land
Auto take off	yes

Maximum speed	10m/sec
Maximum ascent	5m/sec

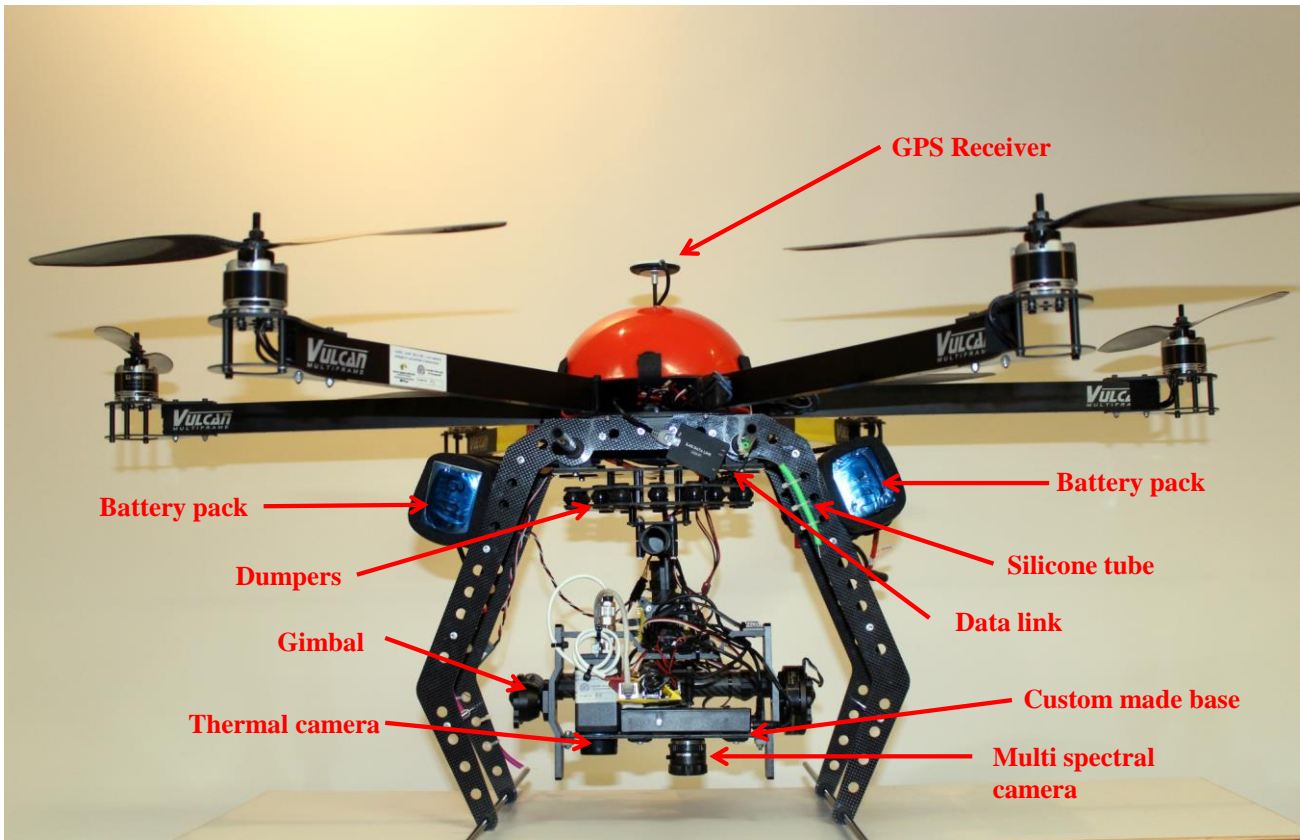


Figure 1. Hexacopter UAV platform with attached thermal and multispectral camera sensors.

2.2 Cameras on board and stabilization mechanism

Two cameras were carried on board. The multispectral imaging camera is the Lightweight Agricultural Digital Camera ADC-Lite (Tetracam, Inc.), specially designed for operation aboard unmanned aerial vehicles and optimized for monitoring vegetation canopy reflectance. Its spectral bands are green (0.53-0.61 μm), red (0.63-0.69 μm) and near infrared (0.78-0.90 μm), and are approximately identical to bands 2, 3 and 4 of the Landsat TM sensor, respectively.

Thermal images were acquired using the A65 thermal imaging camera (FLIR Systems, Inc.). This model addresses the combined demand on high image quality and light device weight for agricultural remote sensing operations with the hexacopter UAV platform. The sensor spectral range is 7.5–13 μm , with an IFOV (Instantaneous Field of View) of 1.31 mRad (milliradians) which corresponds to a spatial resolution of around 6.55 cm when capturing from a 50-meter altitude. The combined weight of the two sensors does not exceed 0.5 kg, making them ideal for the hexacopter UAV platform developed.

In order to ensure that the cameras would acquire vertical images under all flight circumstances, a gimbal was installed between the landing skids of the hexacopter UAV platform (Maytech MTGBM3F5D-B brushless gimbal 3 Axis). The gimbal was mounted on with specially design dumpers in order to eliminate vibration transfer from the hexacopter UAV platform to the cameras that would have resulted to low quality image acquisition.

2.3 Hexacopter UAV platform flight debugging

A problem that has been identified from the test flights was the electrical noise interference between the GPS receiver and the speed controllers. This was due to the initial configuration of the system and the short distance of the two components, which created a magnetic field that did not allow smooth operation. Thus, the appropriate distance was achieved by placing the GPS receiver on a pole that elevated the GPS 12 cm above the system.



Figure 2. Final position with the extension pole

Another problem that was identified was that the cables of the voltage regulators were damaged, due to friction with the aluminum shaft where the cables were mounted. A permanent solution was implemented by covering the cables with a silicone heat-shrinkable material at the point of contact and also foam was installed at the point where the cables exit from the aluminum shaft. In order to further protect the cables inside the aluminum shaft, these were placed in a way that did not allow oscillation at the contact point with the edge of the aluminum shaft (Figure 3).



Figure 3. Cables were not in contact with the metal parts after modification

Another problem observed was that at straight distance of about further than 80 meters from the ground station, there was a corruption in communication with the data link on the hexacopter UAV platform. Specifically, the ground station experienced serious lag in data communication with the hexacopter UAV platform and finally signal loss that resulted in telemetry data loss. Even though the flight plan was executed because it was stored on the autopilot, this was considered a serious issue that could lead to uncontrolled behavior of the hexacopter UAV platform. The problem was restored by transferring the data link to the landing skids and fitting silicone tube to protect the antenna contact with the carbon fiber (Figure 1), which can carry static charges in electronics parts, thus achieving zero loss in a distance of 500 meters in all and in all direction of flight.

2.4 Simultaneous automated operation of both sensors

The hexacopter UAV platform is developed with the ability to automatically trigger both sensors simultaneously in pre-specified waypoints for simultaneous image acquisition, including recording of metadata information such as the GPS coordinates of each image. To achieve this functionality the following technical steps were implemented.

The images from the sensors are stored with the following additional information: geographical location (Latitude, Longitude and altitude) and the exact time of acquisition, information received from the GPS. ADC-Lite has its own triggering process that stores images automatically in the camera's internal storage memory. The triggering process was implemented by a triggering signal which was sent from the hexacopter UAV platform's autopilot system (Figure 4). Also ADC-Lite was equipped with a system to store the coordinates from an external GPS receiver (Figure 4).

While the ADC-Lite sensor was equipped with integrated storage, GPS data input and external triggering system, the FLIR A65 sensor did not include any of the above and a need for an external microprocessor was apparent, in order to interface with the sensor and be controlled on the hexacopter UAV platform automatically. To satisfy that need, a Raspberry Pi model B (Figure 4) was chosen because of its very small size, low power consumption and low cost, which is a necessity for cost effective airborne systems. The Raspberry Pi was connected via ethernet with the FLIR A65 sensor and saved the images on its internal storage upon external trigger. In order for the RaspberryPi to store the exact geographical location of the image taken, the GPS, used also for the ADC-Lite, was connected via USB port. The trigger process for taking images, similar to the ADC-Lite, was signaled from the autopilot.

The Raspberry Pi microprocessor installed on the hexacopter UAV platform run a Debian distribution of Linux OS. Certain modifications were implemented and new software was developed for the system. In order to interface with the camera sensor, as described above, an open source implementation of the GigE Vision/GenICam protocol ⁶ was used, the *aravis* ⁷.

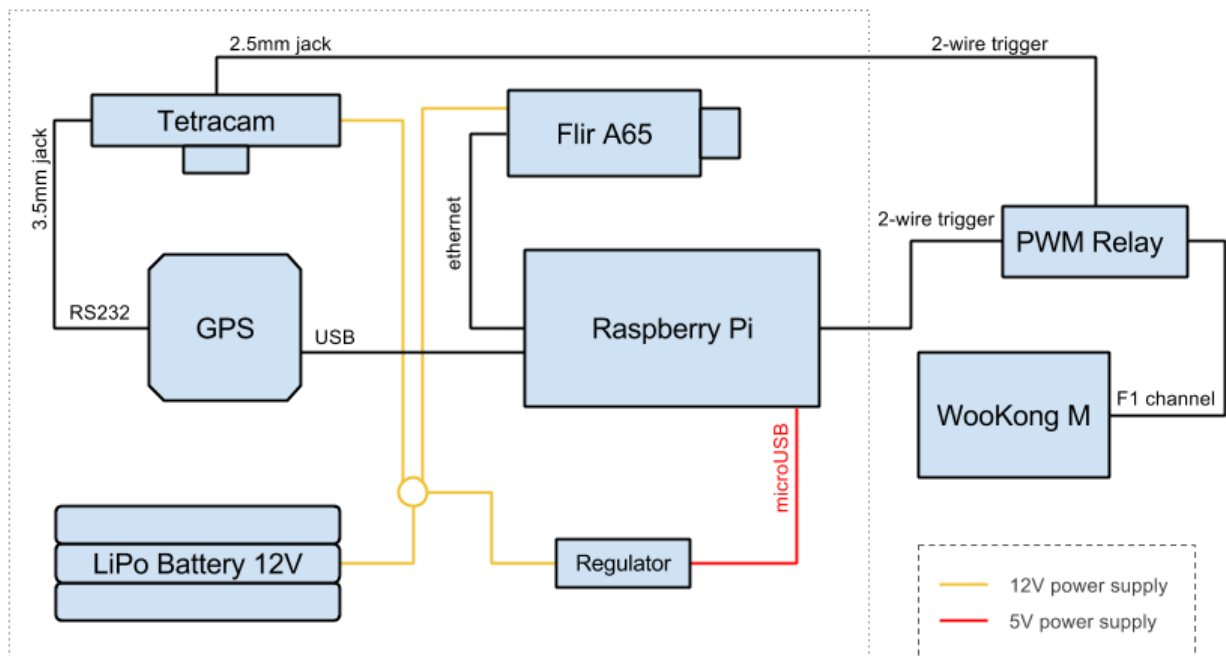


Figure 4. Connectivity diagram of individual components.

In order for the Raspberry Pi microprocessor to be able to communicate with the GPS module and capture coordinates, *gpsd* ⁸ was used as a daemon to constantly collect GPS data. Then, a custom linux daemon was developed in Python ⁹ that was waiting for a trigger signal on one of the microprocessor's digital input pins. After the trigger reached the microprocessor, the daemon used an implementation of *aravis* library, written in Python for simplicity ¹⁰, in order to interface with the FLIR A65 sensor over ethernet and request the capture of a single frame. That frame was then saved to the microprocessor's internal memory, alongside with the corresponding metadata and an output image is produced. Output images could be downloaded later, when the hexacopter UAV platform was on the ground, simply by connecting a laptop to the microprocessor over ethernet.

Output images were stored either as 8-bit monochrome jpeg files or as 14-bit monochrome tiff files on the raspberry. In both options metadata were included in the files (using the *Exif* format), such as GPS coordinates, time of shooting, etc. In the latter case, of 14-bit depth images, it allowed the extraction of the exact temperature per pixel using a formula given by the manufacturer (FLIR A65) in order to transform radiometric signal values to temperature readings.

Finally the Wookong's autopilot ability was used to send a trigger signal on certain events through a PWM (Pulse Width Modulation) relay switch (Figure 4) in order to trigger both sensors simultaneously and achieve electrical isolation between the two circuits. It is worth to mention, that it is possible to program the Wookong autopilot to send a trigger signal automatically (e.g. when the hexacopter UAV platform reaches a pre-programmed waypoint), as well as manually, upon user input. All the above described systems are powered from a 12V lithium polymer battery that is able to power the system much longer than the flight time.

3. OPERATION OF THE HEXACOPTER UAV PLATFORM FOR PRECISION AGRICULTURE

The system was tested over a kiwifruit orchard in Chrysoupoli (Kavala, Greece). The field size was 23.420 m² on flat terrain, and contained a plantation of kiwifruit (*Actinidia deliciosa* var. Hayward). The plants were 19 years old, own-rooted, with trunk height at 1.85m. The training system was a Pergola, with plantation density from 620-640 plants/ha.

Several deployments of the system were tested over the kiwi field in a day with changing overcast (7 November 2014), acquiring nadir images at flying height of 70 and 100m above the ground. The overlap was set to 60% and the sidelap to 40% for all flights.

In order to cover the kiwi field at 70m flying height, 103 images were acquired during two flights of 14.5 minutes each. The same field was covered at 100m flying height with 54 images with a single flight of 14.5 minutes. The images of each flight were stitched in a mosaic using photogrammetric triangulation software (Agisoft Photoscan). Eight ground location targets were used for georeferencing each mosaic, constructed from black and white quarters of a 60cm square printed on paper, alternating with two quarters of aluminum foil (Figure 5). The targets were measured with a Trimble GeoXH GPS, producing an RMSE ranging from 0.37 to 0.48m. The mosaics are presented in Figure 6, while a detail is presented in Figure 7.

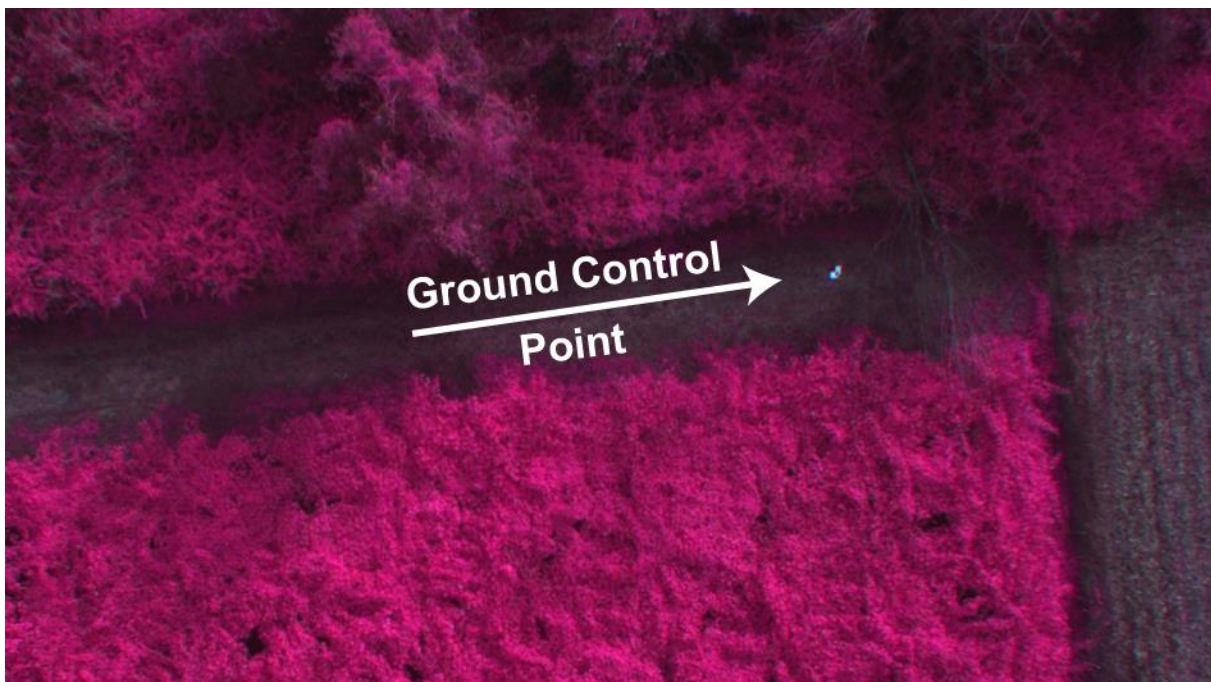


Figure 5: Ground control points used for georeferencing.

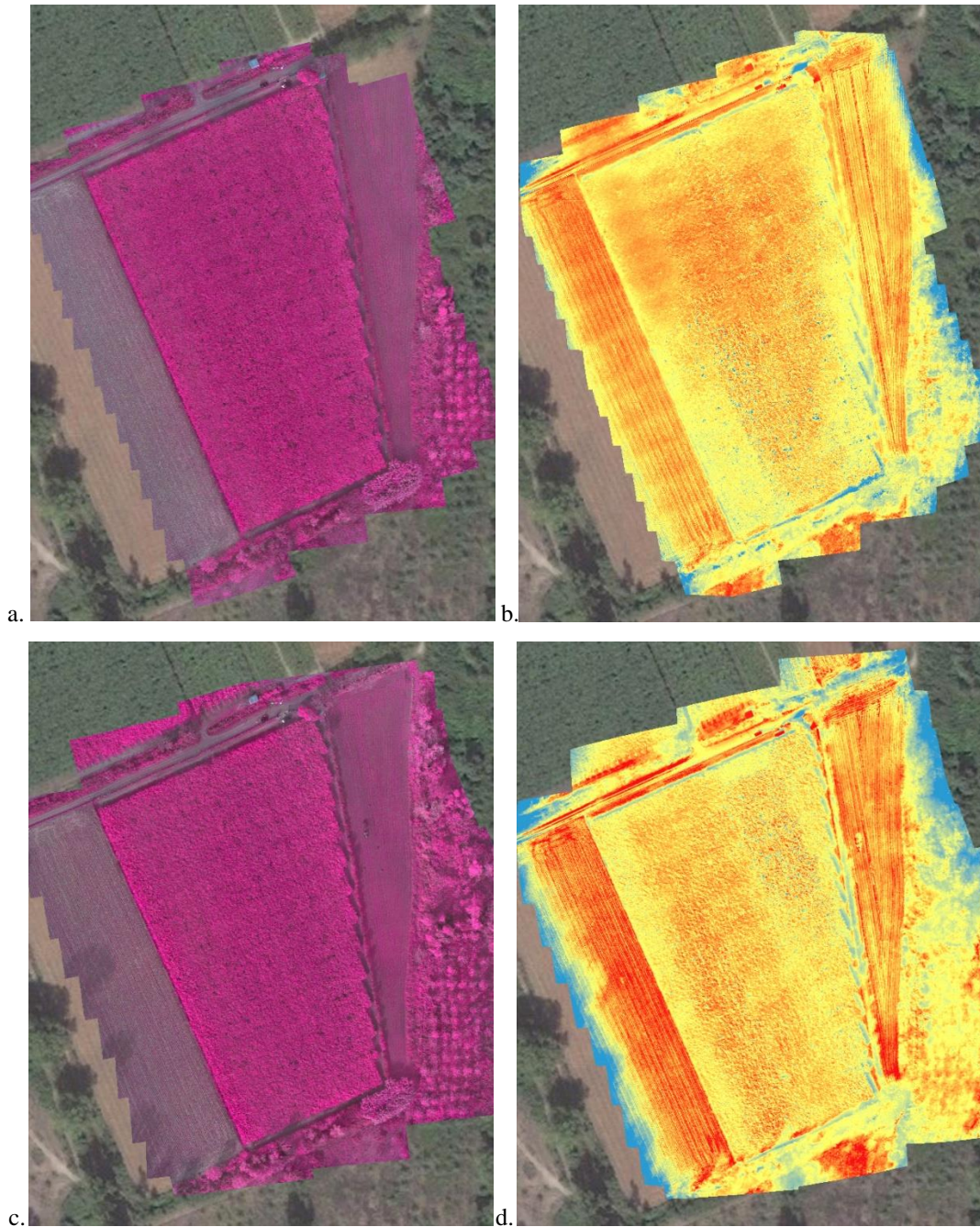
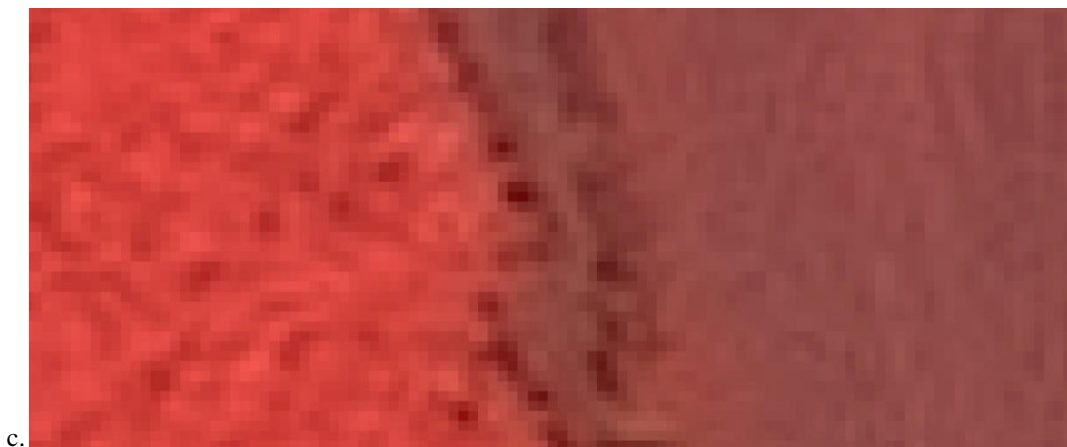
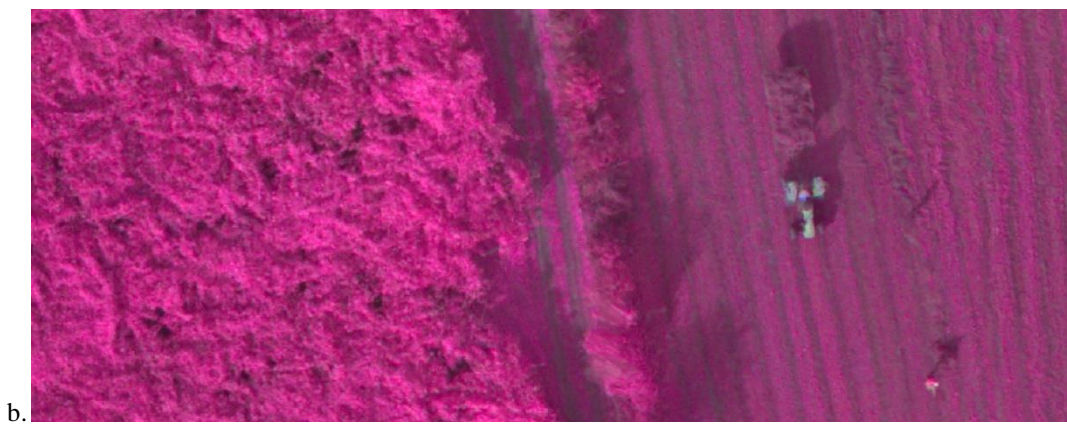
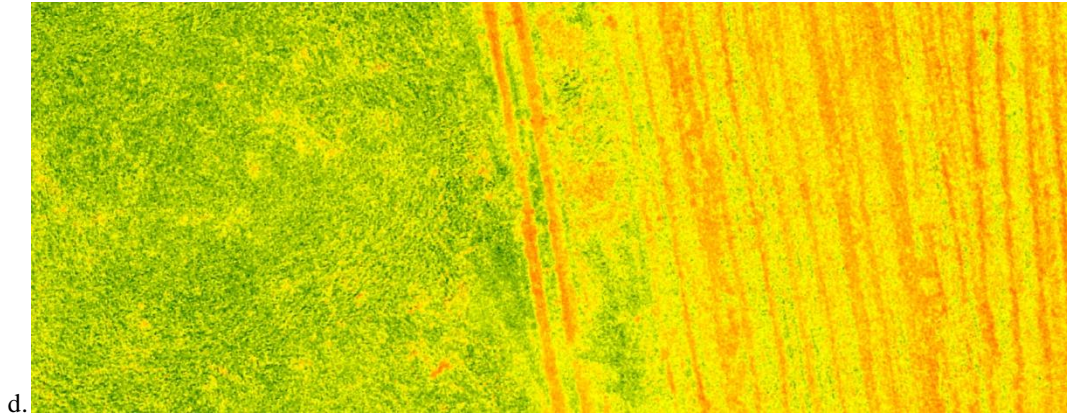


Figure 6: Mosaics over the kiwi field: (a) VNIR 70m, (b) TIR 70m, (c) VNIR 100m, and (d) TIR 100m flying height.

The spatial resolution of these mosaics is 2.8cm in the VNIR and 9.2cm in TIR bands at 70m flying height, and 4cm in the VNIR and 13.1 cm in TIR bands at 100m flying height. In the VNIR wavelengths, the mosaics from both flying heights are of good quality with similar features of the crop visible in both cases. In the TIR wavelength, there is higher homogeneity at 100m, while the thermal difference between the two flights required to cover the field at 70m is evident.

The vignette effect can be seen in both flying heights, but is more prominent at 70m flying height (Figure 6 b). The highest contrast at 100m flying height is due to the sharp shades noted on parts of the canopy due to direct sunlight. In all cases, the spatial detail offered is higher than the highest resolution satellite images, such as the pan-sharpened Pleiades (Figure 7 c).





d. Figure 7: Detail of VNIR mosaics at: (a) 70m, (b) 100m, (c) Pleiades satellite image (0.5m pan sharpened), and (d) NDVI at 70m flying height.

These mosaics will be used in PA applications within the AgroLess project (<http://agroless.eu/>) for photo-interpretation of crop growth, or after digital image processing. Using the VNIR wavelengths of the system, several vegetation indices will be computed to reveal several insights in plant growth: the normalized difference vegetation index (NDVI) (Figure 7 d), the simple ratio index (SRI), and other vegetation indices¹¹. Using the thermal band, the surface temperature of the plants and soil will be estimated, as well as the crop water stress index (CWSI).

Combining these results with concurrent measurements at sample locations in the field, several biophysical properties for the entire field will be estimated, such as nitrogen concentration, photosynthesis, transpiration, and crop yield. In case of crop diseases or insect infestations, its spatial distribution and severity will be mapped within the field.

Finally, a combination of these mosaics with other spatially distributed measurements of soil and plant parameters (electric conductivity, organic matter, and pH) from an on-the-go soil sensor (MSP3, Veris Technologies), will be used in a zonation exercise to produce management zones with distinctive farming recommendations and agrochemical applications.

4. DISCUSSION AND CONCLUSION

The hexacopter UAV platform development process that took place in this work has proven that the commercially available UAVs have become a step closer towards a system with multiple imaging sensors onboard for high accuracy remote sensing that is almost ready to fly. A lot of effort by experts and specialists is necessary to transform a commercially available hexacopter UAV platform to an operational PA UAV platform. Also the developed system proves that current imaging sensors, which have low weight and minimum power requirements, are becoming suitable for installation on a low weight UAV without sacrificing quality in sensors results but they not yet have the suitable interface for the integration on a UAV.

Another issue of great importance on such system is the flight time that is still very limited. Although the transition to electrical motored UAVs from UAVs with thermal engines gained simplicity, reliability, stability, vibration free and also are more environment friendly though the limited battery capacity reduces the flight time. The limited flight time affects the area of the field that is covered by one flight. In the present study a field of 23.420 m² on flat terrain was covered from an altitude of 100m in one flight. In order to cover larger area there are two options either to increase the altitude and reduce image quality or use additional batteries packs. The time lag introduced by the battery substitution procedure between two subsequent flights for a given field scanning operation can cause a certain difference in the illumination and consequently the thermal conditions, rendering the images unusable.

The use of a VTOL hexacopter UAV platform was essential to acquire sharp thermal images, which require low flying speeds when bolometric thermal cameras are used¹². The gimbal was proven important for ensuring vertical images while the UAV is moving, especially against the wind.

The present study has proven the necessity of the development of the hexacopter UAV platform by achieving simultaneous acquisition of good quality VNIR and TIR images. These can be utilized for monitoring of crop growth conditions and assessment of water, nutrient and other stresses in PA applications, where high spatial and temporal resolutions are essential.

ACKNOWLEDGEMENTS

This project “Joint reference strategies for rural activities of reduced inputs” with acronym AGRO_LESS is co-funded by the European Union (ERDF) and National Funds of Greece and Bulgaria under the European Territorial Cooperation Programme, Greece–Bulgaria 2007-2013

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