SPIE REMOTE SENSING 2018 SYMPOSIUM IN EUROPE, BERLIN, GERMANY
10-13 September 2018

COTS UAV-borne Multispectral System for Vegetation Monitoring

IN COOPERATION WITH

- Drone.UA, Ukraine
- Scientific Centre for Aerospace Research of the Earth of Institute of Geological Science of NASU, Ukraine
- Institute of Plant Physiology and Genetics of NASU, Ukraine
- Institute of Physics of NASU, Ukraine
- i4-Flame OU (LLC), Estonia

OUTLINE

- MOTIVATION
- GOALS OF PROJECT
- STUDY CASE
- MATERIALS
- CAMPAIGN
- RESULTS
- CONCLUSIONS
- Q&A

MOTIVATION

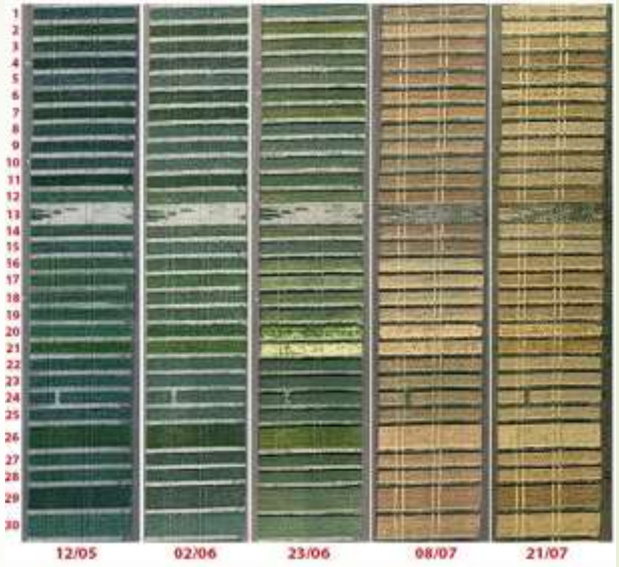
- Due to the changes of the political situation in Ukraine in 2013-2014, traditional commercial aerial imaging service was
  - either temporarily unavailable or
  - not affordable for both state and private agricultural sectors
- The existing solutions did not meet the requirements of the end user
- No suitable high-resolution satellite multispectral imagery was available
- Monitoring of crops and a growth cycle of plants by means of drones or unmanned aerial vehicles (UAVs) was found very attractive in 2014-2015

GOALS OF PROJECT

- The proof-of-concept of in-house lightweight low cost UAV-borne multispectral SWIR (shortwave infrared) sensor (COTS solution)
- The evaluation of performances of airborne tailored SWIR sensor vs. consumer-grade RGB digital camera
- The feasibility study and the comparison of multispectral NIR data vs. Sentinel-2A high-resolution satellite multispectral imagery

STUDY CASE 1: NIR-UAV vs. consumer-grade RGB digital camera

12 May 2015 through 21 July 2015



RGB image

- the Cherkasy region (oblast) in the middle of Ukraine (49.553 N, 28.811 E)
- 50 test plant plots which consisted of winter wheat, summer wheat, summer barley and rye.
- The size of each plot was 25 m by 2 m.
- The spatial resolution of the post-processed orthophotos was 4 cm/pixel.

STUDY CASE 2: NIR-UAV vs. SENTINEL-2A

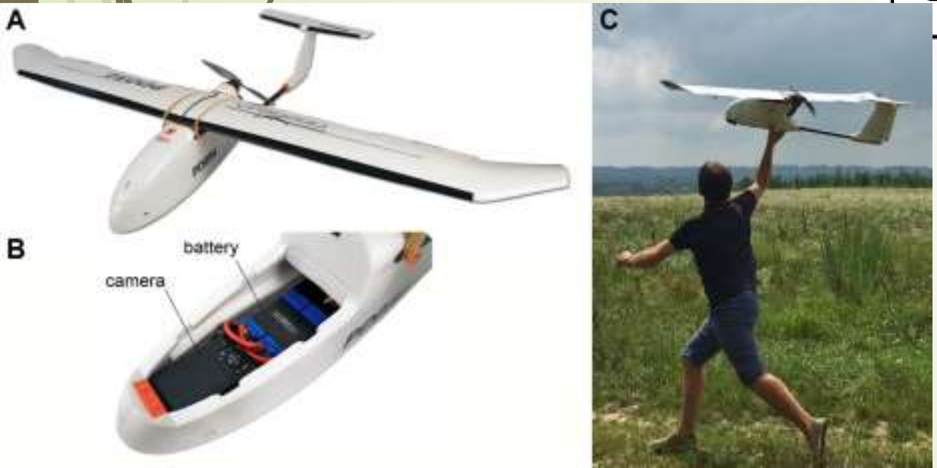
16 June 2016

- the Kyiv region (50.342 N; 31.581 E)
- Sampling on 50 m x 50 m cell grid
- Sentinel-2A multispectral image was delivered preprocessed at the level L1C including corrections of top-of-atmosphere reflectance and geo-correcting

MATERIALS: UAV carrying platform

Skywalker 1900

Feature	Value
Wing span	1900 mm
Fuselage length	1300 mm
Flying weight	2200-2500 g (4.8-5.5 lb)
Air speed	0-15 m/s (0-54 km/h, 0-29.2 knots)
Flying time (autonomous)	0-120 min
Flying attitude	0-200 m (0-656.7 ft.) above ground level
Battery	Li-Po 14.8v 4000-5500 mAh
Motor	Electrical
Radio link	4CH 4SERVO
Takeoff	Hand cast
Maximum anti-wind capability	Level 4
Manufacturer	Skywalker Technology Co. Ltd., China

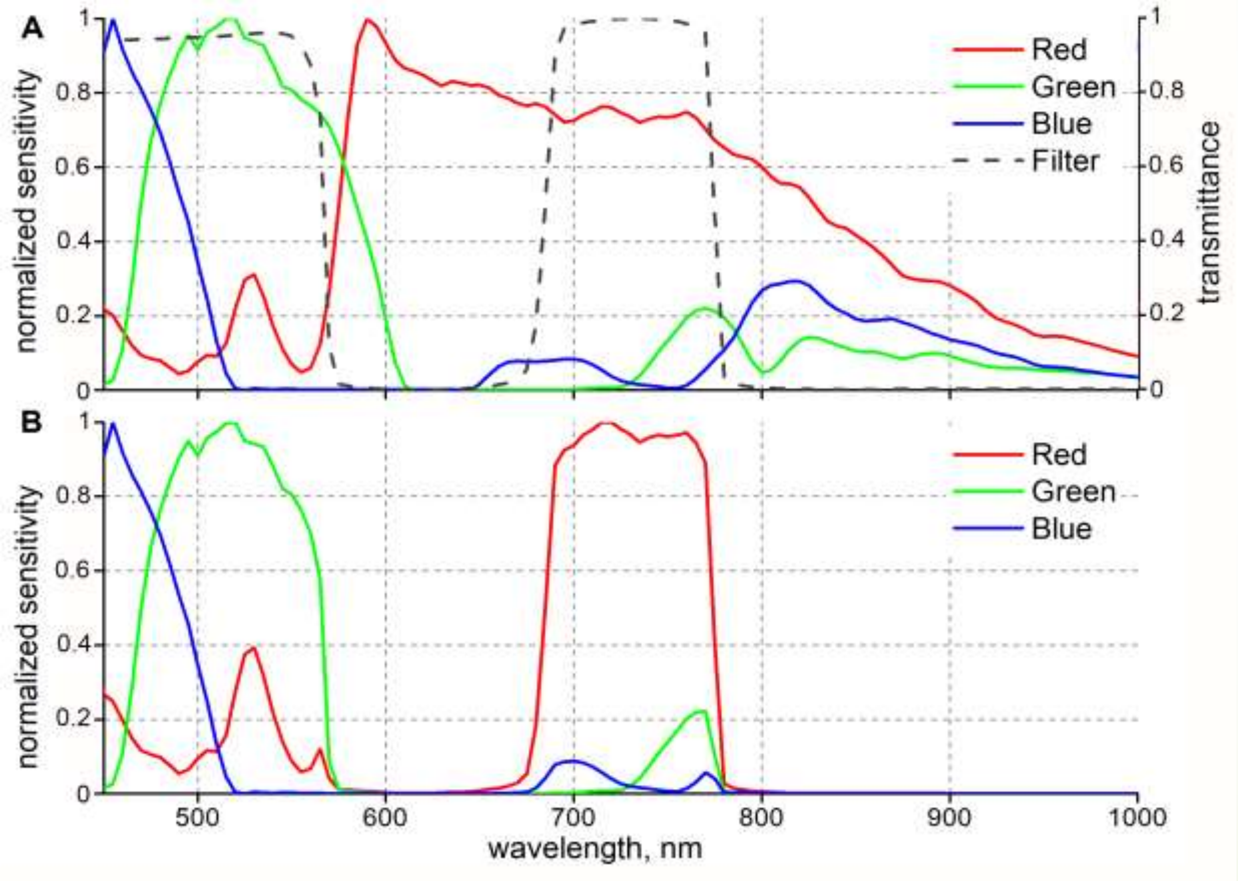


MATERIALS: main RGB camera

Digital camera Canon PowerShot S100

Feature	Value
Sensor type	CMOS
Resolution	4160 x 3124
Effective pixels	12.1 Megapixels, 1/1.7-inch
Color filter type:	RGB
Focal length (35 mm equivalent)	24–120 mm
Focal length (actual):	5.2–26 mm
Aperture range:	f/2.0 (W) / 5.9 (T) – f/8.0 with ND filter
Integrated ND filter:	Yes
Optical image stabilization:	Yes
Exposure	ISO 80–6400

MATERIALS: NIR SENSOR PRE-CALIBRATION



optical spectrum of customized SWIR sensor

- During the calibration for a spectral range of 750–1000 nm, the nominal reflectance values were estimated respectively R–36.5 %, G–28.8 %, and B–60.8 %.
- The measured maximum spectral responses were at 590 nm (R), 450 nm and 815 nm (B), and 515 nm and 770 nm (G).
- Off-the-shelf dual-band-pass filter had two spectral windows: 400–580 nm and 675–780 nm.
- The nominal reflectance values of NIR sensor were estimated as:
  - Red channel Far-Red-NIR (80.3 %)
  - Blue-Green (19.7 %)
  - Green channel NIR (0.5 %) and Green RGB 99.5 %
  - Blue channel NIR (1.9 %) and Blue RGB 98.9 %

MATERIALS: SENTINEL-2A SATELLITE

Sentinel-2A (launched on 23 June 2015)

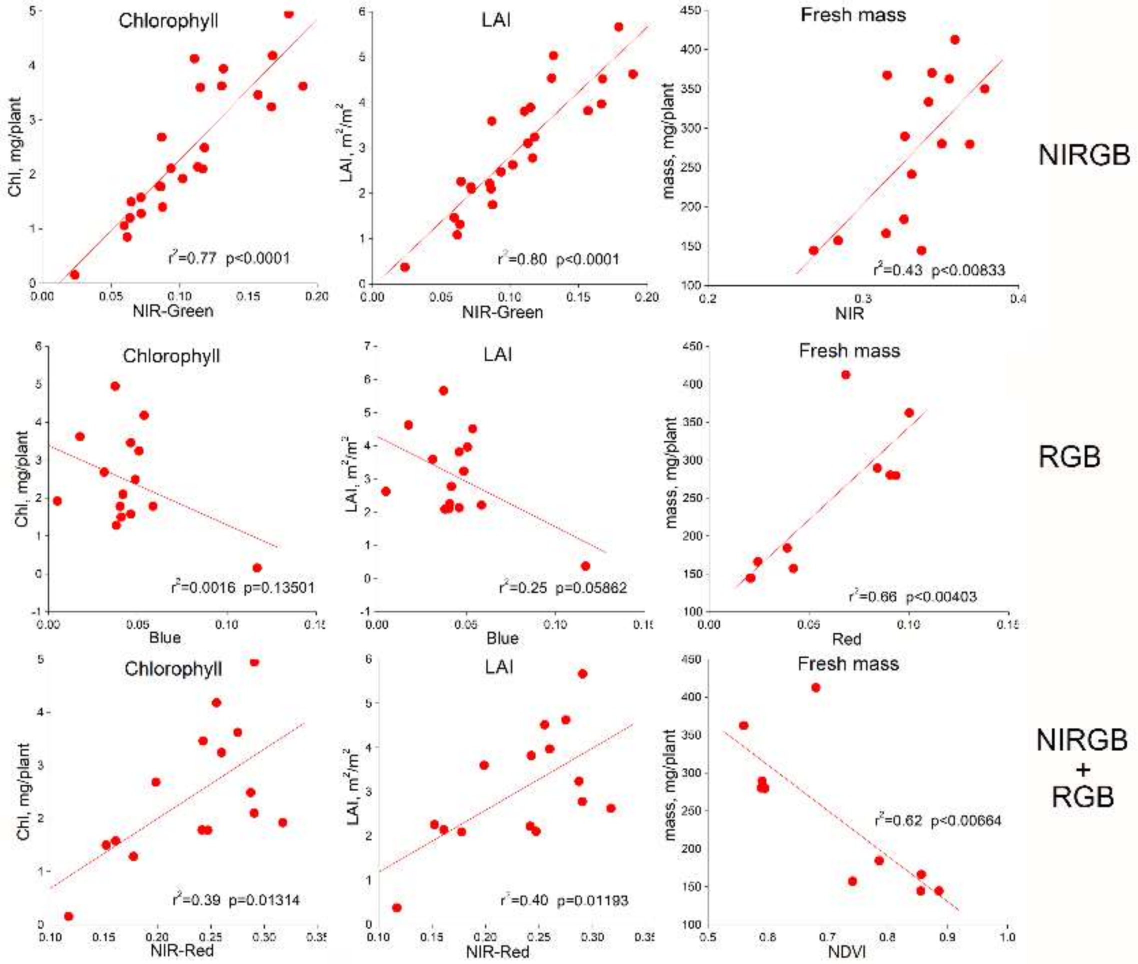
Feature	Value
Operator	European Space Agency
Program	Copernicus programme
Manufacturer	Astrium/Airbus, Thales Alenia Space, France
Thematic areas	Earth observation (climate change, land monitoring, marine monitoring, atmospheric monitoring, emergency management, security)
Orbit	Polar placed, Sun synchronous at 786 km (488 mi) altitude, 14.3 revolutions per day, with a 10:30 a.m. descending node
Coverage area	latitudes 56° south and 84° north
Orbital swath width	290 km (180.2 mi)
Payload	Optical, passive multispectral imager MSI
Scanning mode	Push-broom
Scanning frequency (revisit time)	10 days to the equator for one satellite
Number of spectral bands	four bands at 10 m (32.8 ft.), six bands at 20 m (65.6 ft.) and three bands at 60 m (196.9 ft.) spatial resolution
Wavelengths and bandwidths of MSI	
10 m spatial resolution	B2 (98 nm, central line 496.6 nm), VIS B3 (45 nm, central line 560.0 nm), VIS B4 (38 nm, central line 664.5 nm), VIS B8 (145 nm, central line 835.1 nm), NIR
20 m spatial resolution	B5 (19 nm, central line 703.9 nm), VIS B6 (18 nm, central line 740.2 nm), VIS B7 (28 nm, central line 782.5 nm), VIS B8a (33 nm, central line 864.8 nm), NIR B11 (143 nm, central line 1613.7 nm), SWIR B12 (242 nm, central line 2202.4 nm), SWIR
60 m spatial resolution	B1 (27 nm, central line 443.9 nm), VIS B9 (26 nm, central line 945.0 nm), NIR B10 (75 nm, central line 1373.5 nm), SWIR
Radiometric resolution	12-bit

CAMPAIGN: SWIR-UAV vs. RGB CAMERA

- Off-the-shelf consumer-grade RGB digital camera
- Customized NIR sensor (RGB camera with attached dual-band-pass filter)
- Multispectral imaging was carried out in mid-day under the good weather conditions: stable ambient light conditions, cloud free and sunny with the wind speed of 2-3 m/s
- The flight attitude was 150 m above the ground.
- The flight speed was 10 m/s.
- The image acquisition rate was 3 sec.
- Side-overlap was 70 %.
- For radiometric calibration, 140x140 cm squares of black, grey and white tissue were used.
- Collected images were stored on the onboard SD card in the 10-bit CR2 format, DxO Color Depth Score.

RESULTS: SWIR-UAV SENSOR vs. RGB CAMERA

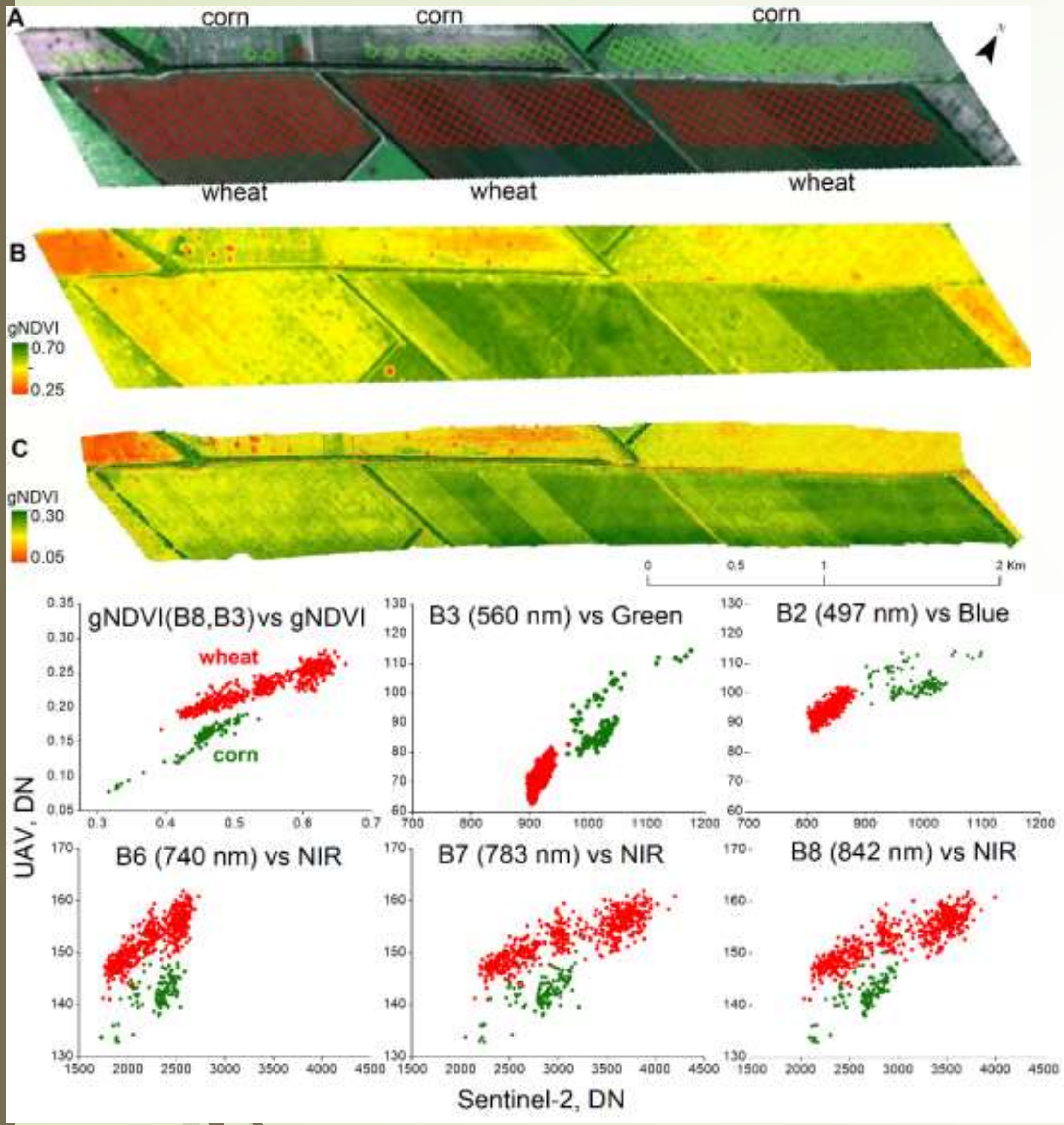
Comparison of vegetation indices and plant growth parameters



- Vegetation indices produced by NIR multispectral sensor, demonstrated the strong correlation with the plant chlorophyll content and the LAI.
- There is the moderate correlation with the plant mass. The highest correlation was observed for gSD (NIR-Green) with r2=0.77 for chlorophyll content, 0.80 for LAI and 0.37 for plant mass. Slightly lower correlation was observed for gEVI (see formula in Table 4) with r2=0.76 for chlorophyll content, 0.79 for LAI and 0.35 for plant mass.
- Most of vegetation indices produced by RGB camera did not reveal significant correlation with any of plant growth parameters. As an exception, single Red band, single Green band and Red-Blue difference revealed moderate correlation with plant mass (r2=0.67 for Red; 0.45 for Green and 0.52 for Red-Blue). Combination of NIR sensor and RGB camera resulted in the moderate correlation (r2=0.39-0.62) with all growth parameters in case of using Red and SWIR bands.

RESULTS: SWIR-UAV SENSOR vs. SENTINEL-2A satellite

Comparison of correlations for wheat and corn



- The relationship between NIR-UAV and MSI in single bands is semi-linear.
- For Blue and Green bands, relationship was slightly higher if comparing to the SWIR spectrum.
- For NIR-UAV sensor, the relationships are species dependent. The regression slopes of the corn points were higher in comparison to the wheat points.
- The relationship between NIR spectrum and Sentinel-2A NIR band is linear.
- Relationship between UAV gNDVI and satellite gNDVI was essentially stronger than relationships between single bands. It also was strictly linear and demonstrated higher species-specificity.

CONCLUSIONS

- Goals were divided into three parts: 1) the proof-of-concept of lightweight low cost UAV-borne multispectral NIR sensor, 2) the evaluation of performances of airborne tailored NIR sensor vs. consumer-grade RGB digital camera, and 3) the feasibility study and the comparison of SWIR multispectral data vs. Sentinel-2A high-resolution satellite multispectral imagery.
- All three tasks were conducted successfully.
- The proof-of-concept demonstrated that the consumer-grade CMOS-based RGB digital camera can be easily converted into the lightweight low cost NIR multispectral sensor by applying an off-the-shelf filter, which cuts off UV and IR radiations.
- The advantages of NIR sensor are obvious: lightweight, low cost, easy to install, easy to maintain, mobile, and less weather dependent if compared to Sentinel-2A satellite-borne multispectral instrumentation.
- Nevertheless, further development of tailored plugins on top of commercial and open-source remote sensing tools for processing and automatical analyses of RGB-NIR data is necessary.