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RPAS and GIS for landfill analysis

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Abstract. Using remote sensing methods to capture environmental contamination is very relevant not only to Lithuania, but also to the whole of Europe. The article examines the Remotely Piloted Aircraft System (RPAS) and its components, in particular aircraft (UAV) mounted camera sensors. From the type of sensor depends what can be identified in the photo. The article presents the geographic informational (GIS) modeling system CALMIM with which the experimental modeling of the landfill territory has been performed. UAV aerial photos captured, modeling described and data analysis carried out.

1 Introduction

1.1 Remotely-Piloted Aerial System

To detect and to monitor parameters of pollution currently satellite systems of European Space Agency (ESA) carried out Sentinel program or navigational remotely piloted aerial vehicle systems (Remotely-Piloted Aerial System - RPAS). Professional Remotely-Piloted Aerial System (RPAS) are equipped with ground control station, specialized software to plan flight missions, control and geographic information system (GIS) for processing and analyzing of collected data. Scheme of RPAS and GIS given bellow in fig. 1.

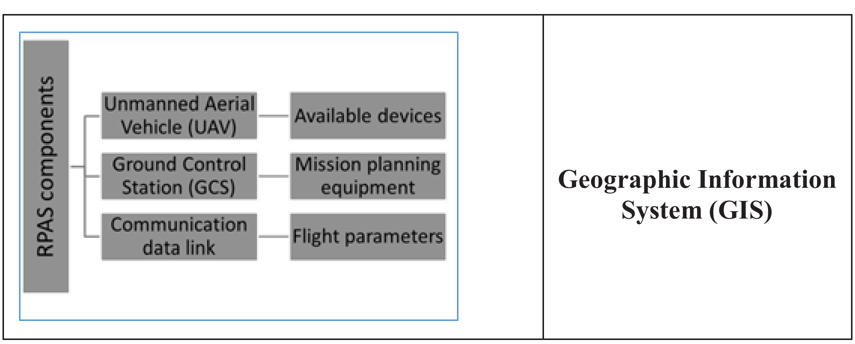

Fig. 1. Components of RPAS and GIS.

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Unmanned Aircraft System‘s components are Unmanned Aircraft Vehicle (UAV), Ground Control Station (GCS) and Communication data link [1]. Systems with specialized software, capable of classic photogrammetry or Structure from Motion (SfM) methods processing are most popular and commonly used [2]. SfM significantly accelerated the development of RPAS systems as it reduced the requirements for the uniformity of image overlays and the calibration of the camera. Currently by body type (construction), UAV divided into two main types – fixed wing and multi-rotor, that mostly influences the way take-off and landing. However general classification also includes altitudes in which aircraft are flying (<330m, 1500m, 9000m, 20000m) and one mission maximum time (5-30 min, 1-2h, 30h). Such a classification for civilian UAVs is taken from the (Fig. 2) [3, 4].

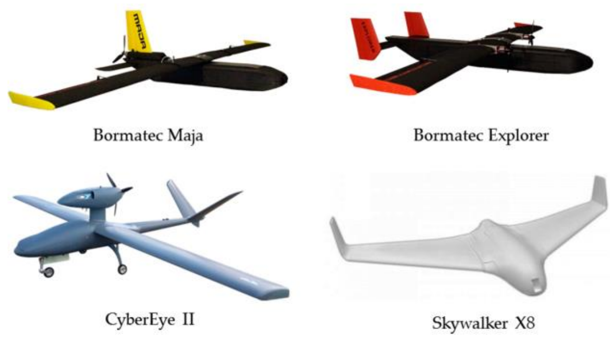

Fig. 2. Fixed wing vehicles for RPAS [5].

The aircraft's flight height, duration, load lift capacity is influenced by its size. These aircrafts can be considered as the category of MINI UAVs (MUAV) [5, 6] These are the vehicles weighting in range of 2–20 kg, normal operating altitude up to 900 m, radius of mission – 25 km. MINI UAV construction airborne vehicles can be used for inspection and monitoring of landfills. With such a large selection of vehicles and their maneuverability, the key to the results is the main camera sensor, recording (recording or broadcasting) the main information for the intended purpose. Based on sensors depends probability to capture the desired information, accuracy and reliability of the information. It could be a normal digital camera, ultra-high resolution, multi-zoom, image stabilizing camera or with other features. Visual material obtained for point of interest from the main sensor and it is possible to reproduce colorful spatial information from overlapped photos. Highly efficient for agriculture and some environmental problems are cameras capturing several bands of spectra – multispectral cameras. For each pixel of each photo they usually capture 5–7 spectral bands, of which 1–2 bands captures part of the NIR wave spectrum, the red and green spectra, and spectrum corresponding color red is divided into several parts, since in case of plant investigation, the so-called Red Edge range is extremely informative (helpful) [5]. Advanced optical systems and precise diffraction grating allow useful part of spectrum to be divided into several hundred narrow bands. In this case, the information is captured by a slightly different principle ("Push-broom") – not by capturing a rectangular picture, but one line of pixels, that represent one band spectrum instead and the entire sensor travels with the aircraft in the desired direction, simultaneously covering same pixels with all different possible bands [6, 7]. There are also attempts to produce small lightweight camera-type spectrometers [8]. However, sensors of right size and weight for unmanned aircraft to carry are not optimized or incomplete variations causes various restrictions for application in systems. Spectrometers have different spectral ranges of continuous coverage, spectral width and accuracy / resolution. In order to detect air pollution at lower part of atmosphere (troposphere), it is necessary to precisely divide spectral range into narrow bands, only then

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it is possible to identify a chemical element. Main and auxiliary sensors need to be adapted and integrated with real-time data processing, storage components, and hardware for secure and reliable wireless telecommunications. It is necessary to resolve the issues between the sensors, global (from the point of view of the earth's surface), inner orientation, also application of suitable coordinate systems. The suitability of these systems for further research, industrial or everyday life application depends on that [8]. Then, as a main sensor SWIR, MWIR, LWIR, LiDAR can be used. As well as small digital devices, when placed on suitable location of UAV's body can detect surrounding instantaneous values of meteorological conditions, CO, CO_2, CH_4 concentration, record and broadcast it. The more complex main sensor used, the more important is the overall calibration of the system [9]. UAVs with digital cameras are currently used for a variety of commercial and non-commercial activities. From relevant (just captured) images, orthophotographic images are created for mapping the area with precise contours, topographic material is updated with generated height information (DSM - Digital Surface Model, Fig. 3).

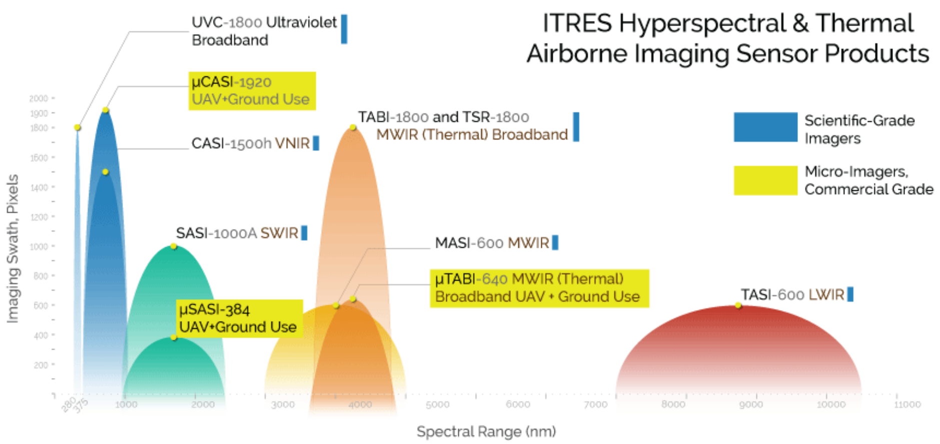

Fig. 3. Airborne Imaging Sensor products.

As well as material for various design tasks and project clarifications, inventory and calculation of volumes, quantities of materials on the construction site, documentation of progress or course of action, mining of natural resources, planning of routes and estimations. Collected material is processed by specialized software, capable of performing classical photogrammetric and previously mentioned SfM photo processing and simulation (modeling) works in GIS [10]. The next section describes CALMIM (California Landfill Methane Inventory Model) modeling system developed to analyze the emission of landfill methane.

1.2 GIS – CALMIM modelling system

During review of the literature noted CALMIM software, that calculates the annual methane emission estimate of landfills for individual sites, based on the key processes that determine the emissions [11, 12]:

- Surface area and properties of daily, intermediate and final cover materials (soil texture);
- Percentage of surface area (%) by each type of layer with engineered gas recovery for the collection (use) of methane gas;
- Seasonal methane oxidation for each layer type and how it is affected by climatic factors.

For diffusive flux, the driving force is the CH_4 gradient through the cover materials, which is a function of the type of cover (daily, intermediate, final), the extent of gas extraction under the cover materials, and methanotrophic oxidation in the cover. The main drive of emission is the methane gradient for each cover material, type, along with dynamic soil moisture and temperature profiles that control methane transport and the microbial oxidation rate of methane in a typical annual cycle.

$$J = (D_e)\times(\delta C/\delta z), \quad (1)$$

where J – diffusional flux, mass/area/time; D_e = effective diffusion coefficient; C is the gas concentration; z – is depth.

CALMIM meets the IPCC (Intergovernmental Panel on Climate Change) level 3 methodology - methane emissions from solid waste disposal sites based on an "approved, higher quality" model. It is Java programing language based modeling software, freely available to users (freeware) and is intended to be a first step in the development of improved, science-based, proven in field tests (approved) models for methane emissions from landfills that could be applied internationally to calculate emissions of a specific landfill site, including seasonal methane oxidation. Based on intervals of 2.5 cm (1 inch) depth and in 10 minute increments, CALMIM calculates daily methane emissions on the substrate for each area of cover (g CH_4/m^2/day). Daily emissions are summed up to receive annual amounts for each layer and landfill site as a whole for a typical annual cycle (kg CH_4/year). Climate-related factors (meteorology and soil microclimate) are automatically downloaded from the Internet, based on the geographic location of the landfill site, by the physical properties of the cover layers. The software is designed to provide a user-friendly interface with a series of input fields for introducing basic information: areas and daily, intermediate, and final cover properties, as well as percentage of surface area for each layer of cover with an engineered gas recovery/collection system (vertical wells or horizontal collectors). Unlike previous models for inventory of methane emissions from landfills, CALMIM does not rely on multi-component first-order kinetic or first-order decay (FOD) equations to model methane generation based on the annual amount and composition of waste present. Original FOD models were all site-specific:

$$Q_T = \sum_{i=1}^{n} 2\, kL_0\, M_i\, e^{-kt_i} \quad (2)$$

where QT – total generation rate from a landfill, mass/time; k – landfill gas generation rate constant, time $^{-1}$; L_0 – methane generation potential, volume/mass of waster; t_i – age of the ith section of waste, time; M_i – mass of wet waste, place at time i; n – total time period of waste placement.

Methane $[CH_4]$ generated, kg/day = $\sum$(CH_4 recovered+CH_4 emitted+CH_4 oxidized+ +CH_4 migrated + ΔCH_4 storage) (3)

Published literature on this topic over decade points out that due to specific local characteristics, the previous reliance on first-class kinetic models for the formation of methane of a landfill as a basis for predicting emissions is not precise, it is necessary to replace better, more scientifically based methodology for the following reasons [13–16]:

- High uncertainty of the theoretical first-class kinetic models, assuming that the waste is homogeneous and due to the hypothetical degradation rate in a heterogeneous landfill environment;

- The methane trajectory is very complex for different landfills (collection, emission, oxidation, horizontal migration, internal capacity), especially in which intensive collection, simulated generation cannot be related to measured emissions;
- A methodology that can be validated in the field by directly measuring emissions is required.

These are not the only flaws of current methodology. Also geometrical accuracy is poor, area calculations are approximately, surface is counted as flat, no break points if cover type is the same. Calculation software does not allow to use any kind of GIS data. Just a point with coordinates, regarding location.

2 Experiments

The object of the experiment is the currently closed Kariotiškės landfill (Lithuania), located in Trakai district, which is 25 km away from the center of capital city Vilnius.

In the course of two decades, 3 million tons of waste have been accumulated in the landfill. At the moment site’s final cover is planted with vegetation. In 2010 a thermal power plant was opened, that generates energy from gas recovered from landfill. In 2011 in landfill sink reservoir an accident occurred, during which about 2000 tons of sludge got into the environment and contaminated at least 1 ha of the nearby forest. In order to avoid such accidents, it is necessary to monitor the condition of the landfill using the most up-to-date monitoring technology. The authors of the article tested two monitoring methods: UAV data analysis and GIS modeling.

Bellow given experiment to digitally recreate closed landfills surface with natural colors. Then experiment was repeated next year, same area remodeled, results compared. Also given examples of modeled other possible locations for landfills and what would be predicted outcome of methane emission depending on location and other parameters.

2.1. UAV data analyses

The shooting of pictures was done in May 2015 and May 2016, using a Trimble UX5 UAV with a Sony NEX-5R digital camera, which was updated before second time. An ortho-photo was generated from the photos using the Trimble Business Center Photogrammetry Module (TBC) software, with an average pixel size (equivalent on the ground - GSD) of 14.4 cm (2015), 3.5 cm (2016) and colored with corresponding RGB value (Fig. 3). Also point cloud was generated from each set of photos, representing real surface - DSM. Each point of which has coordinates in the LKS94 system (1994 coordinate system of Lithuania), assigned value of height in BAS (Baltic system of heights), additionally intensity and color value. Such detailed spatial visual information has not been available for this area until now. In the past only topographic data plan were made, where heights are indicated mostly where measuring objects on the ground, the boundaries of different cover type, the person's visually selected points that characterizes the surface, all of that to be measured only every 8 to 25 meters. Old 2009 the topographic data plan is loaded as a layer on top of orthophotographic images (Fig. 4, 5).

1) 2)

Fig. 4. Kariotiškės landfills territories digital surface model: 1) in year 2015; 2) in year 2016.

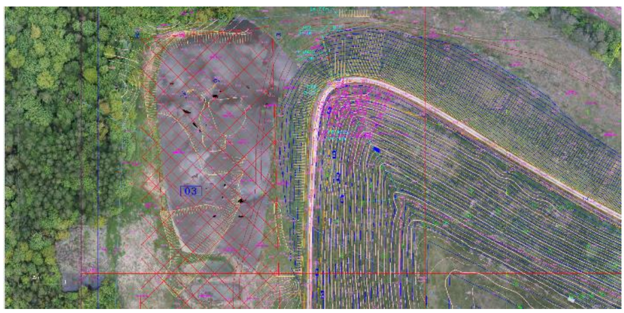

Fig. 5. Orthophotographic photo of Year 2016 with 2009 topographic plan data layered on top.

By comparing visually (Fig. 5), it is evident that the vegetation in the northern part of the territory is livelier, and the slopes of the reservoirs of sediment located in the western part of the territory are changing. Comparison of heights in the cross-section did not show any significant changes. In the future, it is planned to continue this experiment with annual monitoring, but with the help of other sensors: NIR or multispectral cameras, methane sensor TGS 2611/MQ-2 (when flying with multi-rotor unmanned aircraft). There are various types of sensors that can be mounted on a UAV to detect greenhouse gas and VOC traces in the lower part of the atmosphere. The most commonly used methods are electrochemical, photoionization, infrared (IR) laser absorption, semiconductor and catalytic detection. Although each method is fundamentally different, all types of sensors must be able to detect levels of ambient atmospheric concentration and also have a dynamic range that covers the range of gas that is expected to be [17].

2.2. Territory modeling with CALMIM

Using the modeling program with the default values set, the methane emission of Kariotiškės landfill has been simulated for a year. The geographic latitude and longitude of the object (N 54.72° and E 24.96°), the horizontal projection of the surface of the landfill site is expressed in terms of the acreage (1346 acres = 544,7069 ha), the type of cover, the amount of organic matter set to high, the percentage of surface covered with vegetation in the parameters described as 100%, part of the emitted gas, that is collected by engineering systems (75%), cover layer 1 (surface) – material loam - 12 inches (30.48 cm), cover layer 2 – material clay - 12 inches (30.48 cm), cover layer 3 (deepest) – material silty clay loam - 24 inches (60.96 cm). Missing (needed) meteorological conditions are modeled, based by subsystems data of several decades and calculations. They are revised, approved and final modeling of methane emissions runned (Fig. 6).

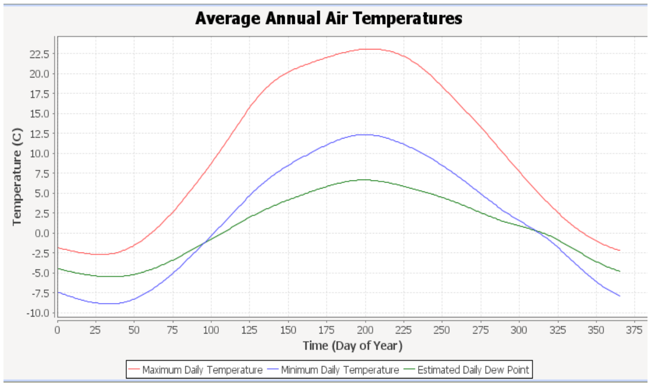

Fig. 6. Annual temperature data used for Kariotiškės landfill: Red line – Maximum Daily temperature; Blue – Minimum Daily temperature; Green – Estimated Daily temperature.

Obtained data by modeling the emission for the first example of the Kariotiškės landfill: 43,99 g/m^2/day CH_4 without oxidation, 100% gets to the atmosphere.

In addition, four situations were modeled, changing the geographic position of the landfill and using new meteorological conditions, changing the cover and percentage of vegetation. From these simulations it has been observed, that after changing the geographical latitude or longitude by 0.1 degrees (less than 20 km distance), yearly air, soil temperature and precipitation remain similar and the amount of methane emissions changes by only 1.8% or 0.8 g/m^2/day. Changing the latitude by more than one degree to the North, with a maximum reduction of the longitude (3.79° West) to the Baltic Sea coast, resulted in an emission reduction of 10.265 % (4.5 g/m^2/day) and, in addition to other meteorological conditions, 0.04% released methane was with oxidation. Also, assumed landfill more to the North-East, in the vicinity of the Latvian border, would result in 9.95% less methane without oxidation and 0.001 g/m^2/day of methane with oxidation. If a similar landfill would exist 5° south and 5° west of Kariotiškės, in Poland, near Krakow, then according to the modeling data, methane emissions would be 22.268 % lower (9.8 g/m^2/day), of which 0.036% of methane with oxidation released. Spokas and Bogner (2011) in the literature are reviewing such geo-modeling (by geographic coordinates/ location) and claiming that location differences of less than 5° are often not worthy of consideration [14].

Another option was modeled. In the modeling parameters, the second layer (middle one) instead of clay was replaced by a special geomembrane. The simulation showed that the CH_4 emission with oxidation became equal to 0. However, the amount of methane released without oxidation into atmosphere decreased by 99.955 % (43.97 g/m^2/day, from 43.99 to 0.02 g/m^2/day). In addition, the advantage is that this efficiency is achieved by reducing the overall cover layer by 27.94 cm (from 121.92 to 93.98 cm). Modeling this case, it was assumed that the engineered gas recovery system collects 75% of the gas produced in the cover. French Environment Agency (ADEME) on the strength of research of K. Spokas and others, has set guidelines, such as: methane emissions are reduced by 90% for the area covered by the geomembrane and an active gas collection or incineration system [10]. Already in 1997 published article, it was written that after testing the properties of the geomembrane (like isolation of the landfill filtrate, stopping of methane formation, static and dynamic pressure) resistance after approximately 8 years of use has not diminished [11, 12]. Following this in next modeled situation, percentage of vegetation covering the site was changed. The examples presented above are modeled with 100% vegetation cover to mimic a closed landfill. Last example modeled with 0% of vegetation covering surface to highlight the influence of living vegetation, all other parameters are unchanged, such as those in the first modeled situation of Kariotiškės landfill. The result showed that total methane amount is slightly higher, but it is the only one from all reviewed simulations, where the amount of methane with oxidation was about 13% of the total methane emission. This is due to the fact that part of the methane is assimilated to the soil's biomass.

3 Conclusion

It is possible to use UAV provided data to generate ortophotographic picture, usable to analyze general situation of landfill site. Special camera can be used to trace various pollutants. According to the above modeling cases, the following conclusions are derived:

1. By changing the geographical location of landfill by 0.1°, about 20 km between two locations in the territory of Lithuania, the resulting methane emissions vary slightly - 1.8% or 0.8 g / m^2 / day due to slight differences in meteorological conditions.
2. Changing the geographical location of the landfill by 3.79°, the maximum extent to the West in the territory of Lithuania from the actual position of the Kariotiškės landfill (about 300 km in-between) results in a 10.265% reduction in methane emissions, corresponding to 4.5 g / m^2 / day, because local meteorological conditions are different, based on 30 year data record.
3. Changing the geographic position of the landfill by 5° (latitude to the south and longitude to the west), to location near the city of Kraków, without limiting to the territory of Lithuania, from the actual position of the Kariotiškės landfill about 620 km in-between), the methane emission is 22.268% lower and corresponds to 9.8 g / m^2 / day, different local meteorological conditions: temperature, precipitation and accumulation of moisture based on 30 year data record.
4. When using the parameters of the first Kariotiškės landfill modeling example and replacing only one layer of cover from clay to geomembrane, from the results of mathematical modeling observed, that the efficiency of this composite material in a particular case is 99.955%, difference in emission is 43.97 g / m^2 / day, the methane emission decreased to 0.02 g / m2 / day.
5. Using the parameters of the first sample of the Kariotiškės landfill and replacing only one parameter, percentage of natural vegetation covering the surface to 0%, from the mathematical modeling results it was observed that this change led to a significantly higher release of methane with oxidation, which amounted to almost 13% of the total methane released.

References

1. E. Mitka, S. G. Mouroutsos. Class. of Dron. AJER **6** (7), 2320–0936 (2017)
2. I. Colomina, P. Molina. Unm. aer. syst. for photogr. and rem. Sens.: A rev. ISPRS J. of Photogr. and Rem. Sens. **92**, 79–97 (2014)
3. A. C. Watts, V. G. Ambrosia, E. A. Hinkley. Unm. aircr. syst. in rem. sens. and scient. res.: Classific. and consid. of use. Rem. Sens. **4**(6), 1671–1692 (2012)
4. C. Suchocki, A. Wasilewski, V. C. Aksamitauskas. Appl. of scan. Techn. in cliff shores monit. The 7th Int. Conf. In Env. Eng. (2008)
5. T. Skauli, H. E. Torkildsen, S. Nicolas, T. Opsahl, T. Haavardsholm, I. Kåsen, A. Rognmo. Comp. cam. for multisp. and conv. Imag. based on patt. filt. Appl. Opt. **53**(13), C64–C71 (2014)

6. P. Baecka, J. Blommaerta, S. Delalieuxa, B. Delauréa, S. Livensa, D. Nuytsa, A. Simaa, G. Jacqueminb, J. P. Goffartb. High res. Veg. mapp. with a novel compact hypersp. cam. syst. The 13th Int. Conf. on Prec. Agric. (2016)
7. S. G. Gupta, M. M. Ghonge, P. M. Jawandhiya. Rev. of Unm. Aircr. Syst. (UAS). Int. J. of Adv. Res. in Comp. Eng. & techn. (IJARCET), **2** (4), 2278–1323 (2013)
8. S. Livens, K. Pauly, P. Baeck, J. Blommaert, D. Nuyts, J. Zender, B. Delauré. A Spatio-Spectral Cam. for high Res. Hypersp. Im. Int. Arch. of the Photogr., Rem. Sens. & Spat. Inf. Sc. **42** (2017)
9. H. Aasen, A. Burkart, A. Bolten, G. Bareth. Gen. 3D hypersp. inf. with lightw. UAV snapsh. cam. for veg. monit.: From cam. Calibr. to qual. assur. ISPRS J. of Photogr. and Rem. Sens. **108**, 245–259 (2015)
10. K. A. Spokas, J. Bogner, J. P. Chanton, M. Morcet, C. Aran, C. Graff, Y. Moreau-Le Golvan, I. Hebe. Meth. mass bal. at three landfill sites: What is the eff. of capture by gas coll. syst.? Waste man. **26**(5), 516–525 (2006)
11. A. W. Eithe, G. R. Koerner. Assessm. of HDPE geom. perf. in a munic. waste landfill double liner syst. after eight years of serv. Geot. and Geomembr. **15**(4–6), 277–287 (1997)
12. H. Eisenbeiss. A Mini Unm. Aer. Veh. (UAV): Syst. overv. and image acq. ISPRS Arch., **XXXVI**-5/W1, 1–7 (2004)
13. K. A. Spokas, J. E. Bogner. Lim. and Dyn. of Meth. Oxi. in Lan. Cov. Soi. W. Man., doi:10.1016/j.wasman.2009.12.018 (2010)
14. J. E. Bogner, K. A. Spokas, J. P. Chanton. Seas. Green. Gas Emis. (Meth., Carb. Diox., Nitr. Ox.) from Eng. Land.: D., Int., and F. Calif. C. Soi. Tech. rep.: W. Man., J. of Env. Qua. **40**, 1010–1020, doi:10.2134/jeq2010.0407 (2011)
15. G. Börjesson, I. Sundh, A. Tunlid, A. Frostegard, B. H. Svensson. Meth. Oxid. in landfill cover soils as rev. by pot. ox. meas. and phosph. fatty acid anal. Soil Biol. Bioch. J. of Env. Qual. **40**, 30:1423–1433 (2011)
16. I. Sundh, G, Börjesson, A. Tunlid. Meth. Oxid. and phosph. fatty acid comp. in a podz. soil prof. J. of Soil Biol. & Bioch. **32**, 1025–1028, (2000)
17. T. J. Schuyler, M. I. Guzman. Unm. Aer. Syst. for Monit. Tr. Trop. Gas. Atm. **8**, 206, doi:10.3390/atmos8100206 (2017)